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SOME ASPECTS OF THE ENVIRONMENTAL IMPACT OF AQUACULTURE IN SENSITIVE AREAS

FINAL REPORT

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Acronyms Used

ACE .... Advisory Committee on the Ecosystem (ICES)
ACF .... Advisory Committee on Fisheries (EC)
ADD................ Acoustic Deterent Device
AGFM............ Advisory Group on Fisheries Management (ICES)
AMA .... Area Management Arrangements
AODA .... Areas for Organised Development of Aquaculture
ASCOBANS .. Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas
ASP................. Amnesiac Shellfish Poisoning.
AZE................ Allowable Zone of Effect
BAP .... Biodiversity Action Plan
BEP .... Best Environmental Practice
CAP .... Community Action Plan
CCRF .... Code of Conduct for Responsible Fisheries (FAO)
CFP................. Common Fisheries Policy
CoP................. Code of Practice
COPASCA ..... Code of Practice for Aquaculture in Sensitive Coastal Areas
COPEGO....... Consorzio Pescatori di Goro (Consortium of Goro Fishermen)
CSD .... Commission on Sustainable Development
DAIN .... Dissolved Available Inorganic Nitrogen
DAIP.............. Dissolved Available Inorganic Phosphorus
DPSIR............ Driving forces, Pressure, State, Impact and Response
DSP .... Diarrhetic Shellfish Poisoning
EC................... European Commission
EcoQO .... Ecological Quality Objective (ICES)
EEA................ European Environment Agency
EIFAC............ European Inland Fisheries Advisory Commission
EIS.................. Environmetnal Impact Statement
EU .... European Union
EUNIS .... European Nature Information System
FAO .... Food and Agriculture Organisation
FEAP .... Federation of European Aquaculture Producers
GFCM............ General Fisheries Council for the Mediterranean
HAB .... Harmful Algal Bloom
HCMR............ Hellenic Centre for Marine Research
HELCOM ...... Helsinki Commission
IBSFC............. International Baltic Sea Fisheries Commission
ICES .... International Council for Exploration of the Seas
IHN .... Infectious Haematopoietic Necrosis
IOC .... International Oceanographic Commission
IPN................. Infectious Pancreatic Necrosis
ISA.................. Infectious Salmonid Anaemia
ISD .... Indicators of Sustainable Development
ITI................... Infaunal Trophic Index
LIC.................. Site of Community Importance (Spanish)

LRP................. Limit Reference Point
MHWM.......... Mean High Water Mark
MLWM .... Mean Low Water Mark
MPA…………Marine Protected Areas
MSC................ Marine Stewardship Council
NCC .... Nature Conservation Council
NGO .... Non-Governmental Organisation
NIS .... Non-indigenous Species
NSA................ National Scenic Area
OECD............ Organisation for Economic Co-operation and Development
OREI.............. Osservatorio dell'Economia Ittica della Regione Emilia Romagna
OSPAR .... Convention for the Protection of the Marine Environment of the North-East Atlantic
PARCOM....... Paris Commission (of the Paris Convention 1974 for the protection of the North Sea and North East Atlantic)
PSP .... Paralytic Shellfish Poisoning
RAC/SPA....... Regional Activity Centre for Specially Protected Areas
RPD................ Redox potential discontinuity
RSI .... Red Sea bream Indoviral disease
SAC................. Scientific Advisory Committee (of GFCM)
SADL .... Spatial Applications Division, Leuven
SCMEE .... Sub-Committee on Marine Environment and Ecosystems (of GFCM)
SCOR............. Scientific Committee on Oceanic Research
SPA................. Special Protection Area
SPAMI .... Specially Protected Areas of Mediterranean Importance
STECF .... Scientific, Technical and Economic Committee for Fisheries (of the EC)
TRP .... Target Reference Point
UWWTD .... Urban Waste Water Treatment Directive
VHS................ Viral Haemorrhagic Septicaemia
WFD............... Water Framework Directive
WS .... White Spot Disease
YH .... Yellowhead disease

Glossary

Alien species: (non-native, non-indigenous, foreign, exotic, introduced, biological pollutants) are species, subspecies, or lower taxon, occurring outside their natural range (past or present) and natural dispersal potential (i.e. outside the range it occupies naturally or could not occupy without direct or indirect introduction or husbandry by humans) and includes any part, gametes or propagule of such species that might survive and subsequently reproduce.

Allowable Zone of Effect: the area (or volume) of seabed or receiving water body in which a regulatory body will allow some exceedance of the relevant environmental quality standard or some limited damage to the environment

Anthropogenic: materials occurring in the natural environment which have originated from human activities.

Aquaculture: the rearing or culture of aquatic organisms using techniques designed to increase the production of the organisms in question beyond the natural capacity of the environment, the organisms remaining the property of a natural or legal person throughout the rearing or culture stage, up to and including harvesting.

Area of occupancy: is defined by IUCN as the area within its extent of occurrence which is occupied by a taxon, excluding cases of vagrancy.

Assimilative capacity: the ability of an area to maintain a healthy environment and accommodate wastes.

Barcelona Convention: the 1996 Barcelona Convention, to which many Mediterranean countries are signatory, aimed at preventing and eliminating pollution of the marine environment in the Mediterranean sea from land-based sources and by dumping from ships and aircraft.

Best Environmental Practice (BEP): the application of the most appropriate combination of environmental control measures and strategies.

Biodiversity (biological diversity): the variability amongst living organisms, including the variability within species, between species and of ecosystems.

Biological carrying capacity: the maximum natural biological productivity of a body of water; if cultivated organisms (shellfish or other species which take their food from their surroundings) exceed the carrying capacity of this water body, then the biological productivity will be depleted and the natural ecosystem damaged.

Biomass (B): is the total quantity of fish in a stock and is used synonymously with stock abundance. Biomass is usually measured as a total tonnage of fish, but could be in numbers or other units to be synonymous with stock abundance.

Carrying capacity: the potential maximum production a species or population can maintain in relation to available food resources within an area.

Chemotherapeutants: compounds used by the finfish industry to treat or prevent various diseases.

Codes of Conduct: describe guidance for aquaculture operations in broad terms.

Codes of Practice: voluntary codes designed to standardised and improve the management of aquaculture.

Depleted: is the status of a fish stock or stock assemblage driven by fishing at very low level of abundance compared to historical levels, with dramatically reduced spawning biomass and reproductive capacity.

Depuration: holding bivalve molluscs such as mussels in sterilised sea water for 48 hours under conditions that allow them to filter normally to remove any bacteria accumulated in the gut; the sea water can be sterilised by ozone or ultra-violet light although the latter is the most common method used.

Ecological footprint: the amount of natural resources required to produce one unit of farmed organisms (e.g. kgs of wild fish required to produce 1 kg of farmed fish); this can also be calculated as units of area per unit of area of farmed organisms; this concept has been applied to organisms which are provided with feed during the farming process (i.e. finfish).
Ecosystem approach: identifying and protecting critical processes in the ecosystem and the interactions between them.
Ecosystem: a community of interdependent organisms, together with the environment they inhabit and with which they interact ; this complex, integrated unit exists in a fine balance, so that even small changes to one part of the system can have knock-on effects on many other components of the system.
El Nino: a disruption of the ocean-atmosphere system in the tropical Pacific having important consequences for global weather: e.g. a rise in sea surface temperatures along the Chile/Peru coast leading to a decline in the productivity of these fisheries.
EN 45011: European Standard for bodies operating product certification systems.
Environmental footprint: the area/volume of the environment impacted by an aquaculture unit.
Escapes: farmed organisms which have escaped from within the confined areas where they are farmed and which may interbreed with natural populations.
Eutrophication: the enrichment of water by nutrients, especially compounds of nitrogen and phosphorus, causing an accelerated growth of algae and higher forms of plant life to produce an undesirable disturbance to the balance of organisms and the quality of the water concerned.
Extensive systems: any system that requires neither supplementary feeding nor a direct input to support of the organisms reared.
Extent of occurrence: is defined by IUCN as the area contained within the shortest continuous imaginary boundary which can be drawn to encompass all the known, inferred or projected sites of present occurrence of a taxon, excluding cases of vagrancy.
Fallowing: practice of leaving cages empty of fish for a period of time to break cycles of disease and/or to allow the seabed to recover; this possible double meaning has created some misunderstandings in the past.
FIFG (the Financial Instrument for Fisheries Guidance): Structural Funds through which the EU attempts to channel financial assistance to those regions which are less developed or in industrial decline, and to support training schemes for those seeking re-entry into employment. Will be replaced by the **European Fisheries Fund** (EFF) over 2007 – 2013.
Fish gap: the extent to which fish of one or more species are available at a level lower than the market demands, because wild fisheries for these species have been closed, partially or fully, in response to wild stocks' falling beneath safe biological limits.
Food conversion ratio (FCR): amount of food required to be provided directly to the farmed organism to produce one unit of organism (applies to finfish; needs to be calculated using the same units, i.e. dry feed compared with dried farmed organism); the biological FCR is the net amount of feed (kgs) used to produce one kg of fish, while the economic FCR takes into account all the feed used, meaning that the effects of feed losses and mortalities, for example, are also included.
Fully exploited: is the status of a fish stock or stock assemblage close to its MSY (see below).
Harmful Algal blooms (HABs): concentrations of phytoplankton producing toxins which can affect human health, oxygen levels in water and which can kill or harm fish, and other vertebrate and invertebrates e.g. by damaging or clogging gills.
Helcom Convention: the 1992 Helsinki Convention, to which many Baltic countries are signatory, aimed at preventing and eliminating pollution of the marine environment in the Baltic sea from land-based sources and by dumping from ships and aircraft.

Integrated Coastal Zone Management (ICZM): a multi-user system designed to establish sustainable levels of economic and social activity in our coastal areas while protecting the coastal environment.

Intensive systems: any culture system that depends exclusively on manufactured inputs (and energy) to organisms.

Interbreeding: mating between two individuals with different genetic traits (e.g. different species, different sub-populations of the same species).

Introgression: incorporation of genes from one population into another leading to the breakdown of co-adapted gene complexes and thus to homogenization of the genetic structure.

Invasive species: means an alien species which becomes established in natural or semi-natural ecosystems or habitat, is an agent of change, and threatens native biological diversity.

ISO 14001: International Standards Organisation quality standards for environmental management systems.

Limit Reference Point: indicates a state of a fishery and/or a resource which is considered to be undesirable and which management action should avoid.

Mariculture: encompasses aquaculture in brackish and sea water as opposed to freshwater

Maximum Sustainable Yield (MSY): is he highest theoretical equilibrium yield that can be continuously taken (on average) from a stock, under existing environmental conditions, without significantly effecting its reproduction success.

MSC: Marine Stewardship Council, an independent body set up to establish basic principals for sustainable fishing and to provide standards for certification of individual fisheries as sustainable.

NASCO: The North Atlantic Salmon Conservation Organisation, established under the Convention for the Conservation of Salmon in the North Atlantic Ocean, which came into force in 1983, whose objective is to contribute to the conservation, restoration, enhancement and rational management of salmon stocks in the North Atlantic Ocean.

Natura 2000 sites: a network of protected areas established under the EC Habitats and Species, and Wild Birds Directives.

NGO: non-Governmental organisations.

Non-native: a species that does not originate in local waters and which has been introduced from other parts of the world by humans, either deliberately or accidentally.

OSPAR Convention: the 1992 Oslo-Paris Convention, to which the UK is a signatory, aimed at preventing and eliminating pollution of the marine environment in the Northeast Atlantic from land-based sources and by dumping from ships and aircraft.

Overexploited: is the status of a fish stock or stock assemblage exploited beyond the limit believed to be sustainable in the long term and beyond which there is an undesirable high risk of sock depletion and collapse.

Ovigerous: egg-bearing.

Polyculture: the deliberate cultivation of more than one species of aquatic organism in close proximity, where each of the organisms in question has a distinct benefit to the commercial process.

Precautionary approach: approach requiring *inter alia* (i) consideration of the needs of future generations and avoidance of changes that are not potentially reversible; (ii) prior identification of undesirable outcomes and of measures that will avoid them or correct them; (iii) initiation of corrective measures without delay, so that these achieve their purpose promptly; (iv) priority to conserving the productive capacity of the resource where the likely impact of resource use is uncertain; and (v) appropriate placement of the burden of proof by adhering to the above requirements.

Precautionary principle: the principle that all responsible parties should act prudently to avoid the possibility of irreversible environmental damage in situations where the scientific evidence is inconclusive but the potential damage could be significant.

Ranching: a sub-category of re-stocking originating from salmon fisheries enhancement programmes. This term is often employed for the restocking of species which are either migratory, returning close to the point of release (e.g. salmon), or non-migratory, remaining for at least a substantial portion of the life-cycle in restricted areas, where they enter the local fishery (e.g. lobster).

Relaying: the sowing out of juvenile shellfish, for example scallops, for on-growing and eventual harvesting.

Restocking: the release of juvenile in mainly coastal, sea areas, lakes or rivers. and where harvesting of the resulting production is carried out by conventional fisheries (professional or recreational). In this document the term 'fisheries' will be used with the same meaning.

River Basin Management Plans: required by the Water Framework Directive, plans subject to review every six years setting out the environmental objectives for water bodies and providing a summary of the measures that are being used to achieve them.

River basin: area of land from which all surface run-off flows through a sequence of streams, rivers and, possibly, freshwater lochs into the sea at a single river mouth, estuary or delta.

Salmonid: members of the salmon family, specifically the Atlantic salmon and the sea trout.

Sea lice: *Lepeoptheirus salmonis* Krøyer and *Caligus elongatus* Nordmann, natural marine ectoparasites of salmon.

Semi-intensive system: a development of the extensive system which requires supplementary feeding (and energy), depending thus both on the natural and supplied feed.

Special Area of Conservation (SAC): sites designated under the Species and Habitats Directive and which are part of Natura 2000 network of protected sites.

Special Protection Area (SPA): sites designated under the Wild Birds Habitats Directive and which are part of Natura 2000 network of European protected sites.

Sustainable development: development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

Target Reference Point: indicates a state of a fishery and/or resource which is considered to be desirable and at which management action should aim.

Transgenic: containing genetic material introduced from another species by techniques of genetic engineering.

Triploid species: normally referred to salmon; fish with three sets of chromosomes (the threads of DNA that carry genetic information) instead of the normal set of two. The extra set of chromosomes prevents development of viable eggs or sperm so, if the triploid fish escape, they can't reproduce.

Visual carrying capacity: the degree to which a particular landscape or area is able to accommodate development or change without significant effects on the character for which it is particularly valued by people or without causing an overall change to its landscape character type; this capacity will vary according to the type and nature of the development or change that is proposed.

Water Framework Directive: This substantial EC Directive requires that all inland and coastal water bodies to reach at least "good status" by 2015. It will do this by establishing a river basin district structure within which demanding environmental objectives will be set, including ecological targets for surface waters. The Directive therefore sets a framework which should provide substantial benefits for the long term sustainable management of water.

Wild land or wilderness: uninhabited and often relatively inaccessible countryside where the influence of human activity on the character and quality of the environment has been minimal.

1 STUDY BACKGROUND, OBJECTIVES AND APPROACH

1.1 AQUACULTURE AND THE ENVIRONMENT IN THE EUROPEAN UNION

1.1.1 Aquaculture in the European Union

Aquaculture is essentially an economic development within small and medium sized enterprises that has grown substantially in most European Union (EU) countries over recent years. This development has been particularly evident in e.g. Scotland, and Ireland [salmon (*Salmo salar*)], the Mediterranean [*sea bass* (*Dicentrarchus labrax*) and sea bream (*Sparus aurata*), together with shellfish] and Ireland, Greece, Spain and France [mussel (*Mytilus edulis*) farming by line or raft] (Read *et al.*, 2000). This trend has paralleled a general decline in catchable wild fish stocks and an increase in consumer demand for fin and shellfish resources (FAO, 1999). Aquaculture therefore provides opportunities to reduce the dependence on wild stocks, to meet increased consumer demand, and to alleviate the economic impact of wild stock decline on coastal communities through the creation of new jobs and businesses (FAO, 1999; MacAlister Elliot and Partners, 1999).

The competitive use of coastal resources has highlighted the importance of satisfactory control measures to protect the natural environment and to safeguard the developing aquaculture industry. In order to achieve sustainable development of the aquaculture sector, several countries introduced regulatory, control and monitoring measures, often without considering the relevance of such measures for the safeguard of the natural environment. Several organisations have documented this situation in several parts of the world and have also recommended procedures to minimise ecological impacts (e.g. FAR, 1993).

Key problems related to modern aquaculture were reviewed in 1992 and there was a proposal to harmonise the previously recommended control procedures (FAR, 1993). The need for the harmonisation of regulatory, control and monitoring procedures has been reinforced in a number of reports (e.g. Cowey, 1995; GESAMP, 1996). However, little further progress has been made and in general, EU countries have continued to proceed independently. An EC Directive 97/11/EC of 3 March 1997 amending Directive 85/337/EEC on the assessment of the effects of certain public and private projects on the environment (EC, 1985), which includes aquaculture in Annex II, emphasises the need for certain projects to undergo compulsory Environmental Impact Assessment (EIA), depending on scale, intensity and local conditions (EC, 1997).

The regulation of the aquaculture sector comes under the remit of the Common Fisheries Policy (CFP) which is particularly concerned with environmental issues. In 1991, the European Commission (EC) produced a review of fisheries activities, the so-called "1991 Report" (EC, 1991), and stated that "the need for rational, responsible, and sustainable exploitation of fisheries, a more effective control of the whole fishing industry, and a broad sharing of responsibilities for managing the CFP". As a result, a new basic Regulation establishing a Community system for fisheries and aquaculture was adopted in 1992 [Council Regulation (EEC) No. 3760/92; EC, 1992a], together with a new regulation the following year establishing a control system applicable to the CFP [Council Regulation (EEC) No. 2847/93; EC, 1993a]. This Regulation strengthened the controls and extended monitoring beyond catching of fish to other aspects of the CFP, such as structures, fish marketing and aquaculture. It is specifically acknowledged in Regulation 2847/93 that "… it is necessary to include rules for the monitoring of conservation and resource management …" and in Article 25 it is stated that "… each Member State shall adopt provisions to verify compliance with the objectives referred to in Article 24 (regular monitoring of activities). To that end, it shall carry out technical controls, particularly in the following areas: (e) development of the aquaculture industry in coastal areas …". The submission of statistics on aquaculture products is also a requirement at European level [Council Regulation (EC) No. 788/96; EC, 1996] and this resulted from an acknowledgement that "… the impact of aquaculture on regional development and on the environment results in an increasing demand for statistics to monitor the development of this sector …".

Using the structural funds system, the Community created the Financial Instrument for Fisheries Guidance (FIFG), a fund which can contribute to measures such as the withdrawal of vessels, fleet renewal, development of coastal waters and aquaculture activities [Council Regulation (EC) No. 3699/93; EC 1993b]. In general, there is an encouragement and financial support at Community level to transfer fishermen from capture fisheries to the aquaculture sector, since there is a requirement for the overall reduction of fishing effort (Council Decision 94/15/EC; EC, 1994a), but for no reduction in the overall demand of marine produce, as acknowledged in Council Regulation (EC) No. 788/96 (EC, 1996). Community operations have been carried out under FIFG since 1994. This has facilitated the development of remote regions of EU Member States (e.g. west of Ireland, west of Scotland, some areas in Greece). In addition, the PESCA Initiative (up to 1999) supplemented the structural aid available under the FIFG (Council Communication 94/C 180/01; EC 1994b).

The potentially adverse impacts of aquaculture are widely documented in the literature (e.g. Ackefors and Enell, 1990; Gowen *et al.*, 1990; Braaten, 1991, Fernandes *et al.*, 2002, Fernandes *et al.*, 2001). A study into environmental variables of interest to the CFP (Huntington *et al*, 2003) determined that there were three key interactions of relevance:

<u>Sustainability of feed resources</u>: the growth in marine aquaculture, especially in the use of carnivorous species such as salmon, bass and bream, exerts an increasing demand for fish meal and oils (ecological footprint). This may have implications for the impact of industrial fisheries upon fish stocks, although this might be felt more by fisheries outside European waters. A number of recent studies by Poseidon Aquatic Resource Management Ltd have also highlighted this issue (Banks *et al*, 2003, Huntington *et al*, 2004, Huntington, 2004).

<u>Eutrophication and HABs</u>: The possible interactions between mariculture and harmful algal blooms (HABs) is of considerable current environmental and public interest in a number of Member States, especially the UK, the Baltic States and Italy. The implications are relevant to human and fish health with both social and economic effects. This relationship exists at two levels (i) the role of intensive finfish mariculture in contributing to HAB events through their ability to input nutrients into the marine ecosystem through uneaten food, faecal material and metabolic by-products and (ii) the impact of HABs resulting from wider anthropogenic and natural systems upon aquaculture systems, especially cultured bivalves.

<u>Genetic integrity of wild stocks</u>: although the currently level of farmed fish being caught in wild catches is only about 1% (compared to 20-25% in Norway), research in Ireland suggests that the potential implication on wild stock fitness are significant. Genetic fitness studies have shown that that farmed fish are only 1-2% as fit as wild fish (from egg to egg) and that wild stock transplanted from a neighbouring river system only 20% as fit as native stock (McGinnity *et al*, 2003. The same study also showed that the lifetime success of escapee / wild hybrids was only 27 to 89% as high if compared to their wild counterparts and 70% of the embryos in the second generation died. The implication of this work is that a small proportion of escapees interbreeding with native wild stocks can have adverse effects on the fitness of the wild population.

However, the actual detectable impacts are not widespread and when present, tend to be localised. It has been agreed that such impacts would be minimised or negated by the adoption of appropriate environmental safeguards including regulatory, control and monitoring procedures (NCC, 1989; Codling *et al.*, 1995; GESAMP, 1996; FAO, 1997). In addition, the aquaculture industry has a vital interest in a clean environment and therefore, in the context of Coastal Zone Management (CZM), there is a definite need to safeguard the marine environment. In 1994 a PARCOM Recommendation was issued on BEP (Best Environmental Practice) for the reduction of Inputs of Potentially Toxic Chemicals from Aquaculture Use (OSPAR, 1994).

The Recommendation includes: (i) national Codes of BEP; (ii) national action programmes incorporating review, development and promotion of BEP; and (iii) the exchange of information between countries on research and development results and experiences with regulatory tools. It does not, however, specifically address the issue of harmonisation. A Code of Practice for aquaculture purposes is also included in US fisheries policies (Boehlert and Schumacher, 1997). Although there are currently requirements to produce national statistics and monitor the environmental impact of aquaculture activities, there is no overall system of monitoring and control that is widely applicable throughout Europe. In relation to this there is much to be learned from the research and development experience in some European countries, and it is proposed here that this specialised experience and expertise is utilised to harmonise regulatory, control and monitoring efforts in EU countries through the production of scientific guidelines for BEP. It is essential that such safeguards are formulated from the best available experience and expertise using the best available science and technology.

1.1.2 Conservation of Special Areas of the Coasts and Seas

In May 1992, the member states of the European Union adopted the 'Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora'. This is more commonly referred to as the Habitats Directive. The main aim of the Directive is to promote the maintenance of biodiversity and, in particular, it requires member states to work together to maintain or restore to favourable conservation status certain rare, threatened, or typical natural habitats and species. These are listed in Annex I and II of the Directive respectively.

Annex I of the Directive sets out natural habitat types of community interest whose conservation requires the designation of special areas of conservation. Guidance on the interpretation of habitat types is given in the 'interpretation manual of European Union Habitats' as approved by the committee set up in Article 20 ('Habitats Committee') and published by the European Commission.

Examples of pan European habitats are presented below:

- Coastal and Halophytic Habitats
- Open Sea and Tidal Areas
- Sea Cliffs and Shingle or Stony Beaches
- Atlantic and Continental Salt Marshes and Salt Meadows
- Mediterranean and Thermo-Atlantic Saltmarshes and Salt Meadows
- Salt and Gypsum Inland Steppes
- Boreal Baltic Archipelago, Coastal and Land upheaval Areas
- Coastal Sand Dunes and Inland Dunes
- Sea Dunes of the Atlantic, North Sea and Baltic Coasts
- Sea Dunes of the Mediterranean Coast
- Inland Dunes, Old and Decalcified

Details on each habitat type can be found at the EU Natura 2000 site:
http://europa.eu.int/comm/environment/nature/nature_conservation/eu_enlargement/2004/pdf/habitats_im_en.pdf

Special Areas of Conservation (SACs) are designated by Member States to meet their obligations under the EC Habitats Directive. They are areas which have been identified as best representing the range and variety within the European Union of habitats and (non-bird) species listed on Annexes I and II to the Directive. SACs in terrestrial areas and marine areas out to 12 nautical miles are designated in the UK under the Conservation (Natural Habitats, &c.) Regulations 1994 (as amended).

The Birds Directive ('Council Directive 79/409/EEC on the conservation of wild birds') complements the Habitats Directive by requiring Member States to protect rare or vulnerable bird species through designating **Special Protection Areas (SPA's).** Together, the terrestrial and marine SPAs and SACs are intended to form a coherent ecological network of sites of European importance, referred to as Natura 2000.

SPAs are classified around Europe to meet their obligations under the EC Birds Directive. These are areas of the most important habitat for rare (listed on Annex I to the Directive) or threatened, and migratory birds within the European Union.

Other European marine conservation designations or initiatives that shall be reviewed within this project, with a specific focus on aquaculture shall include (though not be exclusive to) :

- Marine Nature Reserves (MNRs).
- Natura 2000 sites.
- Ramsar sites.
- World Heritage Sites.
- Biogenetic/Biosphere Reserves.
- European Marine Site.

In terms of consistent data capture on coastal/marine habitats around Europe, The European Environment Agency is developing the European Nature Information System (EUNIS), which includes a comprehensive habitat classification. This has been designed as a tool to facilitate the harmonised description and collection of data on habitats across Europe through the use of criteria for habitat identification. The marine component of the classification, both benthic and pelagic, has been developed using available data, and is currently uneven in the degree of detail in different sea areas.

These issues are addressed in more detail within Section 2.2.

1.2 SPECIFIC BACKGROUND OF THE STUDY

EU aquaculture production grew from 642,000 tonnes in 1980 to 944,000 tonnes in 1990 and reached 1.4 million tonnes in 2005. Its value is currently in the area of €2,500 million per year and its principal products are salmon, trout, sea bass, sea bream, oysters, mussels and clams. Aquaculture constitutes 17% of the volume and 27% of the value of total fishery production of the EU. In some regions, however, aquaculture has a poor public image and is facing criticism for its negative environmental effects.

There is an increasing overlap between marine aquaculture production areas and the protected nature sites of the Natura 2000 network. The Community is committed to this network of sites for certain wild birds, animals and plants, and a range of habitat types. The 'bird' component of Natura 2000 derives from Directive 79/409/EEC and the 'non-bird' component from Directive 92/43/EC. The network is particularly relevant to shellfish farming but there is also overlap with fish farming sites. Aquaculture frequently takes place in wetlands of international importance for birds (frequently found in estuaries and sea inlets). It can also take place in lagoons, large shallow inlets, bays and salt meadows, which are often vulnerable environments, as well as areas used as nurseries by many marine species. It is therefore crucial that the future development of aquaculture incorporates a decoupling of industrial growth from environmental damage.

Environmental protection requirements are being integrated into the Common Fisheries Policy; the Communication from the Commission COM(2002)186 sets out a Community action plan relating to this process. Other relevant background documents are the Biodiversity Action Plan for Fisheries, COM(2001)162 final, Vol. IV and the Recommendation of the European Parliament and of the Council concerning the implementation of Integrated Coastal Zone Management (Recommendation 2002/413/EC) which calls on Member States to take stock of factors affecting the coastal zone, including aquaculture and calls for the Member States to develop strategies to implement the principles of integrated management of the coastal zone.

1.3 OBJECTIVE

The tender document indicates that there are a number of objectives of this study:

- To better understand the interactions between different farming systems and the species / habitat complexes in their vicinity. This in itself needs an understanding of (i) the scale and nature of aquaculture being undertaken and (ii) the site-specific and cumulative impacts that might occur.
- To assess the often apparently conflicting goals of *aquaculture development* and *nature conservation* in order to identify common aims and policy objectives. A practical output from this will be propose measures that should be included in the management plans foreseen in the Habitat's Directive in order to cope with the possible interactions between aquaculture and environment.
- To provide a framework for a practical 'Code of Practice' for use by marine aquaculture operators and regulatory authorities.

The geographic scope of this study is the coastal states of the European Union and does not include freshwater aquaculture. However the lessons learned will be broadly applicable, especially in the case of cage farming in semi-enclosed water bodies.

1.4 APPROACH

As the Terms of Reference (ToRs; Appendix A) require a number of discrete steps to achieve the study objective, a phased approach will be adopted (see text below and Figure 1).

Our approach, which is described in more detail in the methodology (see overleaf), is aimed at providing DG Fish with a practical document that can be easily applied to the both the study's strategic planning guidance as well as the site operator's 'Codes of Practice'.

One of the main issues in designing the approach has been the diversity and wide geographic dispersal of aquaculture facilities through the EU. To address this we have decided to conduct the study at two levels:

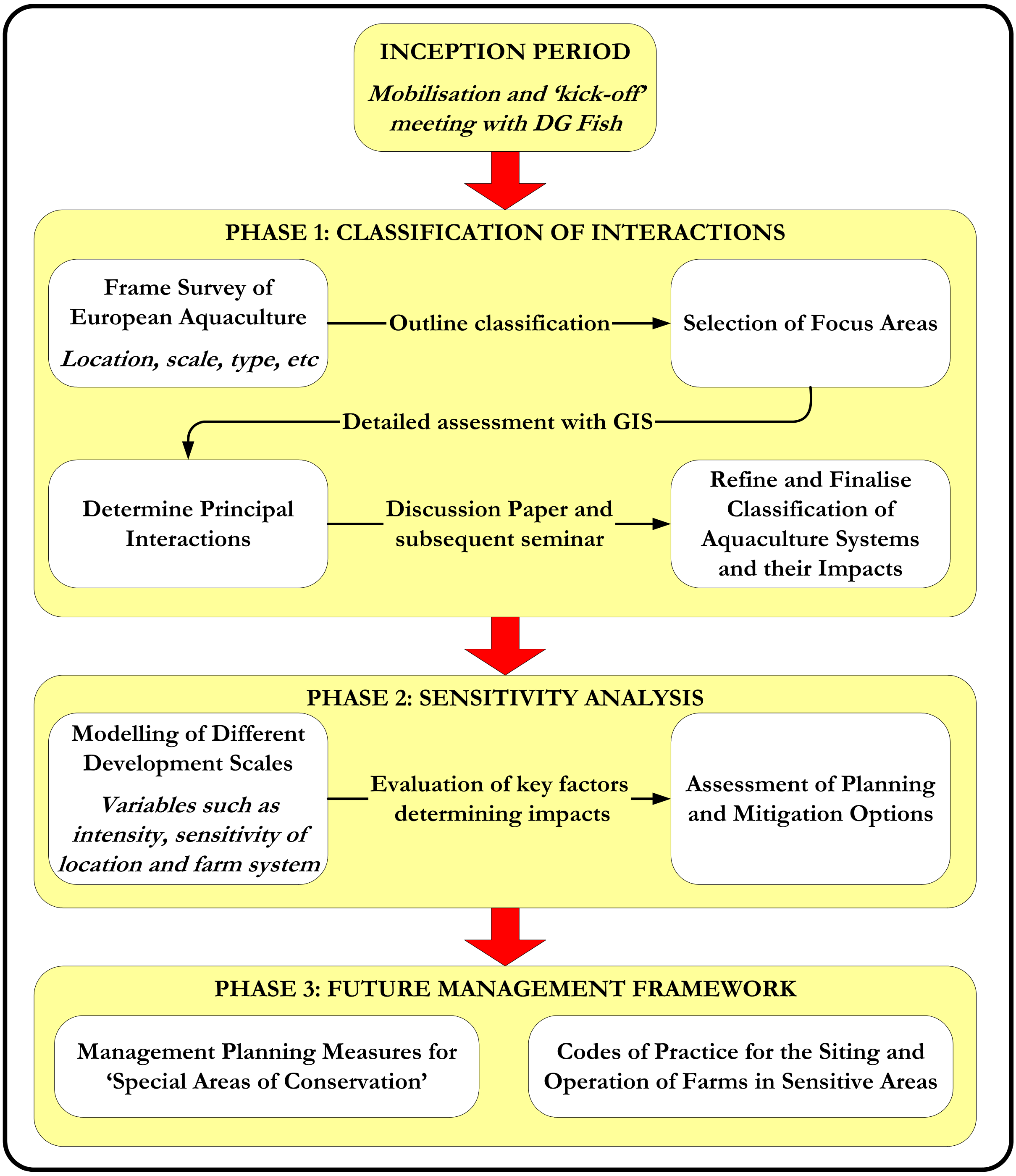
> <u>The whole EU</u>: an initial frame survey will provide a lower definition assessment of the distribution of aquaculture through Europe in terms of its position in relation to sensitive coastal habitats. This will be conducted through the use of a layered Geographical Information System and will provide an outline of the main apparent conflicts and the nature of the aquaculture involved. From this we will select a number of focus areas for a more detained examination at the next level.
>
> <u>Focus areas</u>: a number of focus areas will be selected that reflect the main apparent conflicts identified above. These will then be examined at an appropriate level (e.g. within an identifiable coastal system such as a bay, estuary, lagoonal system or wetland area) where the individual and cumulative impacts of aquaculture will be examined in more detail.

This dual level approach will allow us to ensure that the broad spectrum of aquaculture ventures within Europe's diverse coastal habitats are covered, yet the study provides sufficient detail to ensure that useful and realistic recommendations can be made.

A second important element of our approach is the use of regional specialists to assist in the identification of focus areas, as well as the following characterisation of the interactions between aquaculture and the associated habitats. In particular we have specialists from Greece (cage fin fish culture in bays and open water), Italy (lagoon culture of shellfish and finfish), Spain (shellfish and fin fish culture in the Atlantic coast) and the UK (cage culture of salmonids).

In addition, the study has received the support of a number of eminent specialists from through the EU and Norway who have contributed peer review support that culminated in a workshop in Brussels over 21-22 February 2006.

Figure 1: Phased Approach



1.5 LAYOUT OF THE REPORT

Section 1: Study Background, Objectives and Approach

Provides a 'scene-setting' background, followed by an review of the objective of the report, the approach used and its structure

Section 2: Overview of Coastal Aquaculture in Europe

Initially reviews aquaculture production in the European Union and then examines the typical production systems used in European aquaculture. The report then looks at the regional patterns of coastal aquaculture in the main areas of the EU, focusing on those overlapping with sensitive areas.

Section 3: Environmentally Sensitive Areas of Europe

Examines what constitute a 'sensitive area', then examines the statutory instruments in force through Europe and the EU that enforce nature conservation initiatives. The section then examines which habitats and species are of conservation interest and then screens these to produce a list of those that might be affected by coastal aquaculture and that will be used for analysis over the rest of the report.

Section 4: Spatial Assessment of Interactions between Aquaculture and Environmentally Sensitive Areas

Provides a GIS-based spatial analysis of Member State coastal aquaculture production and 'environmentally sensitive areas.

Section 5: Determination of Principal Pressures on Sensitive Coastal Environments from Aquaculture

Identifies and examines the main environmental pressures originating from coastal aquaculture in Europe. These pressures are examined individually on the basis of two elements: (i) their essential nature and character and (ii) the variables involved in determining their magnitude, significance, duration and distribution.

Section 6: Habitat and Species Description, Ecosystem Importance and Sensitivity

Examines the habitats and species that might be affected by coastal aquaculture (as identified in Section 3). The section provides an initial description of the habitat or species and then conducts a sensitive assessment by examine the reposes of these habitats or species to the the main environmental pressures originating from coastal aquaculture as identified and described in Section 5

Section 7: Risk Identification and Ecosystem Vulnerability

Provides a linkage between Sections 5 (determination of principal pressures) and 6 (sensitive habitats and species) to identify which habitats and species are most vulnerable to which forms of aquaculture. The section then evaluates the main production and environmental variables involved in determining the risks involved and proposes a series of thresholds that might be used for aquaculture in sensitive areas. This is then followed by recommendations for various planning and mitigation approaches.

Section 8: Case Studies

Looks at four case studies from the EU where aquaculture is practiced in environmentally sensitive areas. These review the nature of the activities involved, the nature conservation objectives of the surrounding environment and then reviews the conflicts, issues and management and mitigation approaches that have been taken.

Section 9: Outline Classification of Aquaculture in Environmentally Sensitive Areas

Provides a new classification of aquaculture activities based upon their potential impact on sensitive areas as opposed to the traditional approach of system type and production intensity.

Section 10: Future Management Framework

Reviews the management planning options for aquaculture in the EU's environmentally sensitive coastal areas, with a particular focus on the Natura 2000 network. Then goes on to outline a framework for a 'Code of Practice for environmentally sensitive aquaculture.

2 OVERVIEW OF COASTAL AQUACULTURE IN EUROPE

Aquaculture is "the rearing or cultivation of aquatic organisms using techniques designed to increase the production of the organisms in question beyond the natural capacity of the environment; the organisms remain the property of a natural or legal person throughout the rearing or culture stage, up to and including harvesting[1]".

Although freshwater aquaculture has been practiced in Europe for many centuries, full-cycle[2] aquaculture in brackish and marine waters e.g. mariculture[3] is a more recent phenomenon. Large-scale mariculture first started in the 1970s with the Atlantic salmon, whose large eggs and simple juvenile nutrition permitted the straightforward production of fingerlings for on-growing. Over the same period research was being conducted into the breeding and feeding of other marine species with smaller, pelagic eggs. This has now led to the widespread production of sea bass and sea bream species in the Mediterranean and increasing volumes of more temperate species such as cod, haddock, halibut and turbot as both technological constraints and economics make culture of these species viable.

Table 1: Main Marine and brackish-water finfish species cultured in European waters

Common name		**Scientific name**
Sea bass		*Dicentrarchus labrax*
Sea breams	Gilthead sea bream	*Sparus auratus*
	Silver sea bream	*Sparus sarba*
	Red Porgy	*Pagrus pagrus*
	Sharp-snout sea bream	*Diplodus puntazzo*
	White sea bream	*Diplodus sargus*
	Striped sea bream	*Lithognathus mormyrus*
Grey mullet		*Mugilidae*
Atlantic salmon		*Salmo salar*
Trout	Rainbow trout	*Oncorhynchus mykiss*
	Sea (brown) trout	*Salmo trutta*
Atlantic halibut		*Hippoglossus hippoglossus*
Turbot		*Psetta maxima*
Tuna		*Thunnus thynus*
Meagre		*Argyrosomus regius*
Common sole		*Solea solea*
Atlantic cod		*Gadus morhua*
Haddock		*Melanogrammus aeglefinus*
Common eel (*c.* 5% of production grown in brackish and saltwater, the remainder in freshwater)		*Anguilla anguilla*

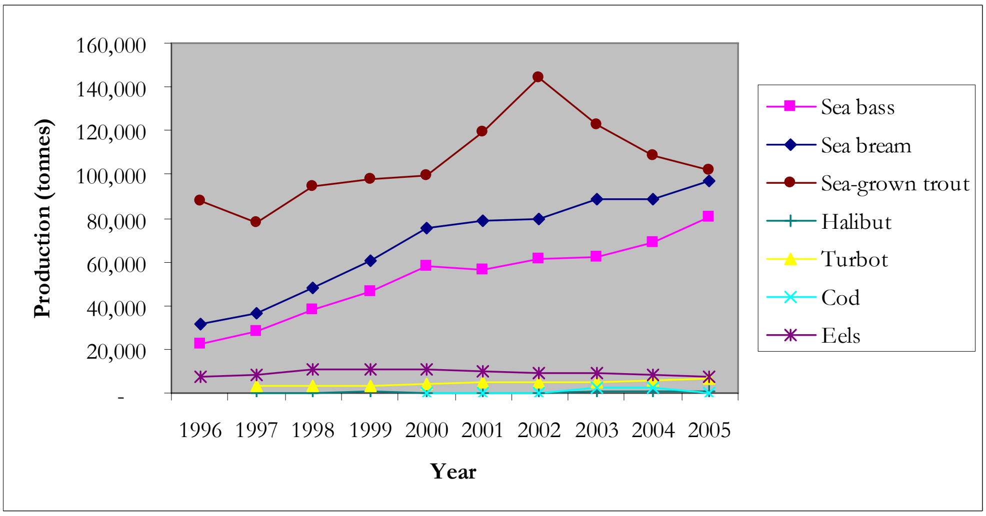
[1] COM(2004) 497 final

[2] Full-cycle culture includes the artificial breeding and rearing of the subject species

[3] Mariculture encompasses aquaculture in brackish and sea water as opposed to freshwater.

An examination of finfish production in Europe (Table 2 below) shows that the production of **Atlantic salmon** still dominates European mariculture in terms of volume, although the growth in EU production is slowing as a result of softening prices and competition from Norway and Chile (see Table 2). European salmon production is largely based around the deepwater bays (lochs and fjords) of Western Scotland, Ireland, Faeroe Islands and Norway. Salmon farming is almost exclusively conducted in sea cages with good tidal flushing, with a trend for larger cage systems with deeper moorings increasingly offshore.

Table 2: Finfish Production in Europe (1996 – 2005)



Species	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Sea bass	22,334	28,433	37,939	46,157	57,811	56,162	61,093	62,060	68,679	80,161
Sea bream	31,132	36,843	48,450	60,831	75,232	79,003	79,767	88,340	88,922	97,060
Salmon	403,284	452,702	502,361	591,068	610,947	640,777	671,655	756,744	717,831	712,271
Sea-grown trout	87,941	78,025	94,250	98,219	99,282	119,431	144,270	122,987	108,198	101,680
Halibut		138	20	503	135	389	350	845	855	905
Turbot		3,118	3,035	3,466	3,873	4,640	5,320	5,107	6,086	6,865
Cod					16	41	50	2,550	2,600	n/a
Eels	7,594	8,293	10,738	11,109	11,033	10,284	9,033	8,715	8,340	7,800
Total	**552,285**	**607,552**	**696,793**	**811,353**	**858,329**	**910,727**	**971,538**	**1,047,348**	**1,001,511**	**1,009,342**

Source: FEAP

Sea bass and sea bream aquaculture have developed more recently and have both tripled in production over the last decade, reaching around 80,000 t and 97,000 t respectively in 2005. Based mainly in Greece, Turkey and Italy, *sea bass* farming expanded rapidly in the late 1990's but has steadied since 2000. *Sea bream* farming, principally of the gilthead sea bream *Sparus aurata* also showed a brief plateau in the early 2000's but continues to increase, largely due to the rapid growth of Turkish production. Both species groups are mainly farmed in sea cages in sheltered areas, although land-based units are also used in France, Spain and Portugal. Italy traditionally used the *vallicoltura* (see Box 1) system but has also moved towards intensive production in land-based and cage farms. Without tidal flushing, cage farm units in the Mediterranean tend to be smaller than salmon cage farms in the Atlantic.

The ranching of bluefin tuna (*Thunnus thynnus*) has expanded rapidly in the Mediterranean over the past five years. At present, there is around 41,000 t cage capacity (for a six month growing period) (ICCAT, 2006), mostly in Spain (29%), Turkey (23%), Croatia (16%), Malta (15%) and Italy (11%) with lower levels of production in Greece and Portugal.

The production of other marine fish such as turbot, halibut and cod is increasing steadily as technical constraints are overcome. **Turbot** and **sole** are mostly produced in land-based farms on the Atlantic coasts of Spain and France, whilst **cod**, **halibut** and **haddock** are farmed in cages in the colder waters of Norway, Iceland and the UK. Halibut juveniles are reared in land-based tanks until they are 30-40 g before they are stocked into sea cages. Unlike salmon, they prefer sheltered areas with little current movement. In Europe, **eel** farms can be found in countries such as Sweden, UK, Netherlands, France, Spain, Denmark and Greece. Due to the complexity of their lifecycle no one has yet managed to successfully breed eels. Instead, eel farms rely on using young eels returning from the Sargasso Sea to grow. Eel culture or farming involves catching juvenile (glass) eels when they enter freshwater and growing them to a marketable size. Whilst 95% of eels are grown in freshwater, Italy, the UK, France and Germany culture eels in brackish (4.5%) and full seawater (0.5%). The three main techniques for culturing eels include the use of ponds, accelerated temperature facilities and recirculation systems.

Common name		**Scientific name**
Mussels	Blue mussel	*Mytilus edulis*
	Mediterranean mussel	*Mytilus galloprovincialis*
Oysters	Native oyster	*Ostrea edulis*
	Pacific oyster	*Crassostrea gigas*
Clams	Native clam	*Ruditapes decussatus*
	Manila Clam	*Ruditapes philippinarum*
	Golden carpet shell	*Tapes aureus*
Scallops		*Pecten maximus*
Shrimp		*Penaeus kerathurus*

Shellfish production in European waters is dominated by production of the **blue or common mussel** (*Mytilus edulis*). Over half a million tonnes is farmed, over half of it by hanging rope culture in Spain. Other significant producers are the Netherlands and France, although production is also increasing in the UK and Ireland. France is also a leading producer of the **European flat oyster (***Ostrea edulis)*, which is mainly framed on racks or poles in the inter-tidal zone.

2.1 COASTAL AQUACULTURE PRODUCTION SYSTEMS AND SITING NEEDS

Traditional coastal aquaculture originated from the Mediterranean, utilising the extensive coastal lagoons to capture migrating fish fry and grow them on for the table. Methods have grown more sophisticated over the past 50 years, leading to the gradual intensification of production as artificial feeding and water management technology have improved. Extensive aquaculture inside coastal lagoons has been traditionally developed, over a period of two centuries, in Northern Italy, along the Adriatic sea coast. At present the activity is developed in about 38,000 ha of lagoons, producing a total of about 2,000 t of fish (sea bass, bream, mullets, eels). In Italy, *vallicoltura* (see Box 1 overleaf) is normally developed by private enterprises with a limited impact on the local communities. On the contrary, Greek lagoon aquaculture employs some 1,500 people, mainly belonging to cooperatives. However, the number of independent Greek lagoon fishermen is increasing, probably due to the high unemployment level in rural areas. In Italy, the production from *vallicoltura* also includes about 15,000 t of Manila clams (Japanese carpet shells) which were introduced about twenty years ago. However, this production comes from the management of what has now to be considered a natural stock, since it no longer requires spat seeding; thus its output should not be included within aquaculture or culture-based fisheries activities.

Box 1: Valliculture in Italy

Valliculture (*vallicoltura)* is one of the most ancient forms of aquaculture in the Mediterranean region. Its origins date back to the first rudimental fish pond and fattening systems used along the Adriatic and Tyrrhenian coasts. This technique was developed by the upper Adriatic populations to exploit the seasonal migrations of some fish species from the sea into the lagoon and delta areas which were more suitable for their growth. The fish returned to the sea because of altered environmental conditions (temperature) of the sea or for reproduction. To exploit these periodic movements, large brackish areas were enclosed to prevent the fish returning to the sea and complex permanent capture systems, fish barriers, were developed consisting of barriers in the channels communicating with the sea to catch the adults. Later, from the simple ponding of fry freely entering the lagoon from the sea, came a man-made seeding of fry fished elsewhere and introduced into the basins to be reared for a few years.

The majority of salmon, sea bass and *sea bream* farming in Europe is carried out in **sea cages**. These are advantageous in that they do not occupy coastal land and are to a certain extent mobile, but may cause localised changes to benthic habitat through the deposition of uneaten food and faeces and in enclosed situations, may contribute to changes in primary productivity. In addition, there may be interactions with natural predators (seals, otters and dolphins, as well as birds). As they are often situated in remote bays, they can be regarded as visually intrusive. There is currently a trend to the use of offshore cages which are large, robust structures moored in deeper waters that allows a better dispersal of waste and are likely to have a lower impact on water quality.

Land-based farming, usually using water pumped into raceways or tanks, can be very intensive and usually requires a high degree of management to operate pumps, water filtration and recirculation systems. Sites are less dependent upon natural conditions, have a smaller footprint and it is easier to control effluent quality.

Semi-intensive pond culture may also depend upon pumped-water supplies, although may be filled and drained during spring tides. The lower density of production usually means that larger areas are employed than intensive land-based farms, and better use is made of natural features such as lagoon areas and salt marshes. They tend to be shallower with lower stocking densities (<1 kg/m^2), making them vulnerable avian and land predators.

The **restocking or ranching** is most developed with marine finfish, including the anadramous Atlantic salmon. This deals with the deliberate release of organisms from hatcheries. In enhancement, fry are released in order to restock wild populations while in ranching the fish are harvested from artificially enclosed areas. These techniques could have important impacts on the genetic diversity of wild stocks (UNEP, 2003).

Bivalve shellfish production depends upon larval animals being placed on a suitable substrate in which to grow. This depends upon environmental preferences of the species, as well as local environmental conditions as well as traditional husbandry practices. In Spain, Ireland and the UK, mussel culture mainly uses suspended ropes hanging from **floating rafts**. This benefits from high primary productivity and low parasite load, although exposure to light might lead to high levels of biofouling as well as susceptibility to avian predators such as Eider ducks (*Somateria mollissima*). This is also a common approach to oyster farming in the Mediterranean. Mussels and oysters can also be produced through **bottom culture**, although it is often more suitable for clams and scallops that prefer to bury themselves in a soft substrate. In France particularly, as well as areas of the UK, oysters are cultured on **racks** in the inter-tidal zone as they produce regularly shaped shells preferred by raw half-shell consumers. Whilst most shellfish aquaculture is conducted in coastal waters, some bivalve production takes place in shallow **lagoons** and ponds, especially in the Mediterranean, including salt marsh areas converted into holding **ponds**.

In Portugal most of the bivalve culture takes place in intertidal areas where the substrate is managed to create a good environment where coarser and finer sediments are intermixed. They are then overlayed and beds are managed and periodically cleaned from settling macroalgae. Main species cultured are *Ruditapes decussatus* and *Tapes aureus*.

Table 3: Mollusc Production (Capture and Culture) in Europe (1996 - 2003)

Species		**Country**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
Queen scallop	*Aequipecten opercularis*	UK	5,676	8,249	6,002	5,207	8,707	10,793	7,336
		France	595	637	2,574	3,475	5,989	4,260	4,287
		Ireland	7	5	29	3	13	58	39
		Sub-total	***6,278***	***8,891***	***8,605***	***8,685***	***14,709***	***15,111***	***11,662***
Pacific cupped oyster	*Crassostrea gigas*	France	147,164	136,214	137,050	133,608	107,453	113,296	115,008
		Ireland	3,628	5,369	6,555	5,031	4,909	5,444	4,830
		Netherlands	1,200	2,510	3,128	2,000	2,857	2,789	3,000
		UK	1,100	764	1,148	1,117	846	801	1,107
		Spain	980	1,043	682	595	675	591	715
		Portugal	618	578	754	448	768	249	325
		Germany	75	75	85	85	85	85	85
		Sub-total	***154,765***	***146,553***	***149,402***	***142,884***	***117,593***	***123,255***	***125,070***
Blue mussel	*Mytilus edulis*	Spain	188,969	261,146	261,996	247,730	246,018	260,043	248,839
		Denmark	90,765	108,329	96,215	110,618	122,487	110,873	92,534
		Netherlands	93,244	113,185	100,800	66,800	48,600	45,061	56,200
		France	59,322	52,155	61,164	69,479	63,235	60,410	56,143
		Ireland	18,057	19,596	16,111	25,660	30,373	31,703	39,289
		Germany	22,330	31,213	37,912	24,122	11,638	8,018	28,549
		UK	32,121	20,390	17,507	18,575	32,237	34,318	22,321
		Sweden	1,428	491	925	513	1,495	1,468	1,812
		Portugal	501	334	374	321	287	589	1,702
		Sub-total	***506,737***	***606,839***	***593,004***	***563,818***	***556,370***	***552,483***	***547,389***
Mediterranean mussel	*Mytilus galloprovincialis*	Italy	103,430	117,270	118,510	138,200	138,160	138,249	142,736
		Greece	35,188	20,924	37,092	24,796	26,188	21,974	31,601
		France	12,078	11,778	10,923	7,205	18,012	12,591	13,004
		Slovenia	38	44	37	44	88	83	135
		Spain	29	<0.5	19	18	24	11	4
		Sub-total	***150,763***	***150,016***	***166,581***	***170,263***	***182,472***	***172,908***	***187,480***
European flat oyster	*Ostrea edulis*	Spain	2,758	2,861	3,791	3,535	3,903	4,624	2,396
		France	2,518	2,314	2,012	2,009	1,782	2,191	2,098
		Denmark	24	6	8	9	23	528	876
		Ireland	1,133	716	1,376	266	431	280	873
		UK	643	1,098	418	443	756	718	797
		Netherlands	34	192	86	200	122	75	250
		Greece	372	107	49	128	145	82	57
		Sweden	3	2	4	2	1	2	6
		Sub-total	***7,485***	***7,296***	***7,744***	***6,592***	***7,163***	***8,500***	***7,353***
Great Atlantic scallop	*Pecten maximus*	UK	18,728	20,119	19,135	19,548	19,546	18,763	19,204
		France	14,786	13,165	14,070	14,086	16,918	20,385	18,596
		Ireland	663	718	1,530	1,640	1,462	1,207	1,799
		Netherlands	188	408	306	249	274	473	536
		Belgium	208	224	247	292	340	432	521
		Spain	675	498	383	580	229	255	191
		Sub-total	***35,248***	***35,132***	***35,671***	***36,395***	***38,769***	***41,515***	***40,847***
Grooved carpet shell	*Ruditapes decussatus*	Portugal	3,286	3,358	1,472	2,432	2,744	3,112	3,022
		France	321	1,010	1,956	584	1,319	778	824
		Spain	2,298	2,436	2,335	1,503	1,088	699	196
		Ireland	23	3	3	3	130	-	102
		Sub-total	***5,928***	***6,807***	***5,766***	***4,522***	***5,281***	***4,589***	***4,144***
Japanese carpet shell	*Ruditapes philippinarum*	Italy	40,000	48,000	50,000	53,000	55,000	41,139	25,000
		Spain	140	1,630	1,826	2,737	1,278	442	1,484
		France	.	.	.	507	1,015	719	750
		Ireland	200	233	121	92	91	100	154
		UK	36	31	29	29	36	36	23
		Sub-total	***40,376***	***49,894***	***51,976***	***56,365***	***57,420***	***42,436***	***27,411***
Clams (various species		France	2,893	5,822	4,638	4,280	4,696	5,860	8,001
		Spain	5,422	6,494	5,401	2,890	2,668	3,620	1,354
		UK	142	13	67	15	91	43	909
		Ireland	-	-	-	301	126	83	834
		Portugal	741	1,007	493	395	398	322	393
		Sub-total	***9,198***	***13,336***	***10,599***	***7,881***	***7,979***	***9,928***	***11,491***
TOTAL		**TOTAL**	**916,778**	**1,024,764**	**1,029,348**	**997,405**	**987,756**	**970,725**	**962,847**

Source: FAO

Table 4: Finfish Mariculture Systems used in Europe

Level	Types	Typical species	Characteristics	Siting Needs
Intensive	Land-based tanks and raceways	Salmon, sea bass (FR) and sea bream (FR), turbot, sole and eels	Often very high intensity production with controlled flow rates and recirculation. Small environmental footprint, often covered and possible to control effluents.	Small area of low-lying coastal area adjacent to a clean, deep-water for pumping ashore.
	Sea cages	Salmon, sea bass, sea breams, halibut, cod	Relies on good initial siting as dependent upon site environmental conditions. Permit less control than pump-ashore systems but sites are less costly and movable.	Requires current speeds 10 to 50 m s^{-1}, with an ideal site running at 20 to 40 m s^{-1}. Water depth must allow net clearance and mooring. Must be sheltered.
Semi-intensive	Pond culture	Mullet, sea bass and sea bream, shrimp	Larger environmental footprint than the above, either situated above the high tide in low-lying coastal plains (e.g. salt marshes in Portugal). Usually used for lower density culture of shrimp or finfish e.g. mullets, sea bass and sea bream. May require extensive effluent settlement areas.	Larger areas of low-lying coastal land. Usually above sea level to allow pond drainage (thus requiring pumping) but maybe filled by spring tides. Soil needs to have good clay content to retain water unless expensive liners are used. Needs access to good quality water.
Extensive	Lagoon culture	Mullet, sea bass and sea bream, shrimp	Traditional methods (e.g. Italian *vallicoltura*) using natural fry and no or limited supplementary feeds. May require compartmentalisation of natural lagoon areas.	Based on naturally occurring lagoon areas, especially in the Mediterranean area. Have been increasingly compartmentalised and controlled to improve productivity.
	Ranching	Salmon, lobster, cod	Restocking of species which are either migratory, returning close to the point of release (e.g. salmon), or non-migratory, remaining for at least a substantial portion of the life-cycle in restricted areas, where they enter the local fishery (e.g. lobster).	Critical migratory or life cycle points for stocking. Little or no permanent infrastructure.

Table 5: Shellfish Production Techniques in Europe

Types	Typical species	Characteristics	Siting Needs*
Suspended rope culture	Mussels, oysters (Mediterranean)	Ropes, covered with spat kept in place by nylon nets, are suspended either from rafts, wooden frames or from long lines of floating plastic buoys.	Clean water, absence of avian predators,
Bottom culture	Mussels, oysters, scallops	Seed mussels are relayed in suitable grow-out sites.	Oysters and mussels need a firm substrate whilst scallops and clams require a softer muds and sand. Low levels of predation from crabs and starfish.
Rack culture	Oysters	Oysters are laid out on wooden trestles or racks laid out in the intertidal zone.	Firm sediment to support equipment, vehicle access
'Bouchot" culture	Mussels (France)	Uses a series of wooden poles as supports, onto which the mussels are transplanted for on-growing	
Ponds	Oysters, shrimp	In France, a special treatment ('*affinage*') may be applied for the supply of top quality oysters - prior to selling these are placed in former salt marshes which have been converted into ponds ('*claires*')	
Lagoons	Clams	Juveniles are released into controlled marine areas (lagoons, salt pans, large ponds or 'parks' in the open sea)	Adequate water supply to ensure the supply of nutrients and the flushing of pseudofaeces.

** Generic bivalve siting requirements include (i) clean water free from domestic or industrial effluents and pathogens, (ii) optimum water temperatures (9-26°C native oysters and clams, 9-29°C Pacific oysters and Manila clams, 0-27°C for mussels and 7-20°C for scallops, (iii) optimal salinity (25-35‰ native oysters, native and Manila clams, 20-30‰ Pacific oysters, 20-35‰ mussels and >30‰ for scallops, (iv) high levels of primary productivity and (iv) low occurrence of excessive turbidity.*

Table 6: Atlantic salmon production in Europe

COUNTRY	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Faroe Islands	10,000	5,950	15,000	25,000	36,981	31,440	46,013	45,000	52,526	36,645
France	400	400	-					5,000	8,000	10,000
Greece	12	12	2							
Iceland	2,880	2,850	3,500	3,360	3,750	3,480	5,600	1,471	3,700	7,500
Ireland	14,500	13,872	14,500	15,200	18,287	17,800	22,412	21,423	17,920	14,001
Norway	249,200	296,000	316,000	343,000	412,001	423,001	420,000	460,000	520,000	512,000
Spain	1,250	1,100	1,100	300	300	300				
Sweden	25	100	100	3						
UK	70,060	83,000	100,000	115,000	119,431	135,000	146,429	142,961	161,748	157,000
Total	**348,327**	**403,284**	**450,202**	**501,863**	**590,750**	**611,021**	**640,454**	**675,855**	**763,894**	**737,146**

* Provisional

Table 7: Sea Bass Production in Europe

Country	1996	1997	1998	1999	2000	2001	2002	2003	2004*
Cyprus	150	58	204	298	300	300	421	500	500
France	1,500	1,650	2,500	3,150	3,600	3,000	3,500	3,700	3,800
Greece	9,000	12,000	17,000	20,000	23,000	24,000	28,000	26,000	27,000
Iceland			5	10	20	50	3	80	
Italy	3,900	4,300	5,200	6,600	8,100	8,900	9,000	8,900	9,000
Malta	396	500	600	500	600				
Portugal	556	902	1,000	849	1,080	700	800	1,500	1,500
Spain	900	829	1,408	1,670	2,300	1,950	3,180	4,530	6,200
Turkey	3,000	6,300	8,660	12,000	17,877	15,546	14,339	15,000	15,000
Total	**19,402**	**26,539**	**36,577**	**45,077**	**56,877**	**54,446**	**59,243**	**60,210**	**63,000**

* Provisional

Table 8: Sea Bream Production in Europe

Species	Country	1996	1997	1998	1999	2000	2001	2002	2003	2004
Gilthead Seabream	Cyprus	600	768	830	986	1,200	1,300	1,260	1,500	1,500
	France	1,000	1,000	1,250	1,000	1,400	1,700	1,500	1,100	1,300
	Greece	12,000	14,000	19,000	28,000	36,000	37,000	42,000	49,000	49,000
	Italy	3,000	3,500	4,600	4,800	6,000	6,800	8,000	7,800	8,500
	Malta	1,156	2,000	1,900	1,900	1,600	1,500	1,500		
	Portugal	1,150	1,700	1,900	1,595	2,060	2,000	2,200	2,500	2,500
	Spain	4,700	5,530	6,330	7,600	8,300	10,685	10,960	12,440	13,500
	Turkey	9,000	7,500	10,150	11,000	15,460	12,939	11,681	17,841**	24,000
Gilthead seabream		***32,606***	***35,998***	***45,960***	***56,881***	***72,020***	***73,924***	***79,101***	***92,181***	***100,300***
Silver seabream	Cyprus	26	25							
Red Porgy	Greece				100					
Sharp-snout seabream	Greece				1,000	0				
White seabream	Italy			300	350	400	400	400	400	400
Striped seabream	Cyprus			25	28	100	100			
Sea breams grand total		**32,632**	**36,023**	**46,285**	**58,359**	**72,520**	**74,424**	**79,501**	**92,581**	**100,700**

* Provisional ** 2003 figure for Turkey estimated

Source : FEAP

Table 9: Halibut, turbot, sole and cod production in Europe

Product	Country	1997	1998	1999	2000	2001	2002	2003	2004*
Halibut	Iceland		20	50	30	100		95	105
	Norway	138		453	100	100	100	500	500
	UK				5	189	250	250	250
Halibut Total		**138**	**20**	**503**	**135**	**389**	**350**	**845**	**855**
Turbot Juveniles	France		3	3	4	4	5	5	5
	Spain		1						
Turbot Juveniles		**-**	**4**	**3**	**4**	**4**	**5**	**5**	**5**
Turbot	France	950	850	900	1	700	750	700	900
	Iceland							32	95
	Ireland			8	12	15	30	50	50
	Netherlands							75	75
	Norway	113						270	270
	Portugal		265	475	510	540	540	540	540
	Spain	2,055	1,920	2,083	3,350	3,385	4,000	3,440	4,150
Turbot Total		**3,118**	**3,035**	**3,466**	**3,873**	**4,640**	**5,320**	**5,107**	**6,080**
Sole	Spain						60	52	60
Sole Total		**0**	**0**	**0**	**0**	**0**	**60**	**52**	**60**
Cod	Norway							2,500	2,500
	UK				16	41	50	50	50
Cod Total		**0**	**0**	**0**	**16**	**41**	**50**	**2550**	**2550**
Grand Total		**3,256**	**3,059**	**3,972**	**4,028**	**5,074**	**5,785**	**8,559**	**9,550**

Table 10: Eel production in Europe

Product	Country	1996	1997	1998	1999	2000	2001	2002	2003	2004*
European Eels	Belgium/Luxemberg	150	150	150	40					
	Denmark	1,200	1,700	2,468						
(no size	France	160								
classification)	Germany	140	150	150		150	150			
	Greece	350	312	500	500					
	Hungary					13		48	20	20
	Italy	3,000	3,100							
	Netherlands	1,800	1,800	3,250						
	Norway	200	200	200						
	Portugal	200	200	200	200	200	200			
	Spain	210	266							
	Sweden						230	230	230	230
	Turkey						200			
Sub-total		***7,410***	***7,878***	***6,918***	***740***	***363***	***780***	***278***	***250***	***250***
European Eels	Belgium/Luxemberg					20	20			
- 130/170g	Denmark				2,415	2,400	1,900	2,100	150	150
	Greece					250	550	500	500	500
	Hungary				7		64			
	Italy			1,200	1,200	1,100	900	700	700	600
	Netherlands				3,000	3,250	3,250	3,450	3,150	3,375
	Spain			260	280	340	315	335	315	351
Sub-total				***1,460***	***6,902***	***7,360***	***6,999***	***7,085***	***4,815***	***4,976***
European Eels	Denmark				285	275	200	200	1,900	1,900
- >300g	Greece					50				
	Hungary				12		40			
	Italy			1,900	1,900	1,700	1,500	700	700	600
	Netherlands				800	750	750	750	1,050	1,125
	Spain			10	20	85	15	20	0	0
	Sweden	184	215	250	250	250				
	Turkey		200	200	200	200				
Sub-total		***184***	***415***	***2,360***	***3,467***	***3,310***	***2,505***	***1,670***	***3,650***	***3,625***
Grand Total		**7,594**	**8,293**	**10,738**	**11,109**	**11,033**	**10,284**	**9,033**	**8,715**	**8,851**

* Provisional

2.2 REGIONAL PRODUCTION PATTERNS

In addition to examining the published data on coastal aquaculture discussed above, this study conducted a more detailed analysis of production within EU Member States to identify production patterns down to NUTS 1 and where possible, NUTS 2 regional levels[4]. This information will be used to identify broad overlaps with 'sensitive habitats' in the next Section.

2.2.1 North East Atlantic

The NE Atlantic is characterised by temperate waters, albeit warmed by the Gulf Stream and consists of the Iberian, Celtic Biscay shelf and North Sea Large Marine Ecosystems (LMEs). These LMEs are influenced by the North Atlantic Drift in the North, and by the Azores Current in the South as well as the North Atlantic Oscillation (NAO). The region undergoes a seasonal climatic cycle that strongly affects the pelagic ecosystem through forcing factors: sunlight exposure, heat input, and mechanical forcing on the surface due to wind. Many of the coasts are exposed to south westerly gales, so aquaculture tends to be found in sheltered bays, fjords and sea lochs.

Portugal

Regional production patterns: the marine aquaculture in **Portugal** is located along the coastline from the North to the South. The production consists mainly of bivalves bottom culture in tidal estuaries and lagoons (clams and oysters) and sea bass, sea bream, sole, turbot and cuttlefish farming operating in semi-intensive and intensive system, both in ponds as well as in tanks.

The North region is located in a quite exposed coastline where currents improve the water renewal but relevant habitats such as sand dunes, estuaries and lagoons are present. Between Caminha and Viana do Castelo there are four structures installed at present to produce mussels in open sea, using the same system as in the Galician bays (Spain, see below). In the vicinity of the port of Viana do Castelo there are farms which grow turbot and hatcheries of sea bass in an intensive regime and mono-culture systems in tanks inland.

Around the Centro region, fish farms are located in land using tanks in open circuit and ponds in areas that were previously salt works, which produce sea bass and sea bream. At the Arade River estuary there is a farm operating in the semi-intensive regime to produce sea bass and sea bream and there is also oysters and clams production using the water circulation ditches of the fish unit. The turbot production in intensive regime uses small quantities of water taken from artesian wells with the effluent being treated and disposed into the soil. In the Ria de Aveiro, at the Canal de Mira, which is an important for wintering birds, there is cultivation of molluscs in extensive and semi-extensive regimes.

In the region Lisboa and Vale do Tejo, in the Sado estuary, there are fish farms dedicated to the fattening of sea bass and sea bream in an extensive regime in ponds and lagoons. Hatcheries of molluscs are also found in intensive regime inland using tanks and raceways for the young bivalves. After several months the young bivalves are transported to estuary zones where they grow and reach a marketable size. There is extensive aquaculture in reconverted old salt works, as well as intensive culture of sea bass and sea bream in cages outside the Sines port.

In the Alentejo region sea bass and sea bream are cultivated in an extensive regime in the Mira estuary. Statistics for the Algarve total aquaculture production clearly show that this is the most important aquaculture region in Portugal, especially for the bottom culture of shellfish. Sea bass and sea bream are cultivated in the Algarve region; where juveniles are grown in a semi-intensive

[4] NUTS (*Nomenclature des unîtes territoriales statistiques*) is a three level hierarchal regional classification within each EU Member State.

regime in compacted earth tanks and ponds, using old salt works located within lagoons. Submersed structures made up of nets and cages coupled to the sea net are used for the ongrowing of the species caught in the sea net, supported by a main and secondary vessels. The aquaculture production takes place almost exclusively in the lagoons, of which the Ria Formosa is by far the largest and most in important. Fish aquaculture is also an important activity in this area, ranging from the traditional exploitation of naturally stocked fish in converted salinas (disused saltworks) or channels that are closed to prevent the escape of juveniles, to semi-intensive rearing of fish in earth ponds and intensive rearing in concrete tanks.

Ria Formosa is considered of European importance for biodiversity and therefore was proposed as a NATURA 2000 site under the protection of Habitats and Birds Directives. It is classified as a RAMSAR site for the protection of wetlands. About 90% of the area is a Natural Park (Ría Formosa Natural Park) since 1989.

Aquaculture in Portugal is still mostly an artisanal activity where the bulk of culture is carried out in extensive or semi extensive systems, using old salt works, coastal ponds or intertidal areas within the lagoons. There are some examples of poly-culture. The intensive production is quite reduced but it is moving to incorporate technological advances, therefore it is necessary to take into account measures to reduce the potential impact to preserve the sensitive areas where they are located.

The particular sitting requirements in Portugal for extensive and poly-cultivation in lagoons may require compartmentalisation and control so that productivity is improved; supplementary feeds and auxiliary pumping may be necessary. Intensive mussel cultivation in rafts needs clean water and sufficient phytoplankton, protected deep water zones to permit to carry out production tasks.

Aquaculture in Portugal is important socio-economically since it does generate several jobs and contributes to mitigate the reduction of income from fishing-related activities. The aquaculture activity has provided around 5,700 positions, most of them full time (more that 5,000 come from shellfish cultivation in the Algarve, represented by very small companies grouped in two Associations of Producers). The annual turnover generated by the aquaculture activity is around € 65,260,000 where more than 80% comes from the Algarve region.

Spain

Regional production patterns: marine aquaculture in **Spain** produced in the *Atlantic coastline* is essentially divided in shellfish production (essentially mussels) and fish production (turbot, sea bream and sea bass) although there is a clear difference between the marine cultivation in the North region and in Andalusia. The Galicia region has several natural areas included in Natura 2000. The *rías* shape the characteristic profile of the Galicia´s coastline. *Rías Baixas* with sand-flats exposed during the low tides and estuaries, used for bottom shellfish cultivation, coastal lakes and dunes which are key refuges for wintering birds, and where are located the Atlantic Islands National Park of Galicia. *Rías Altas* has rocky shores and cliffs, dunes and shallow bays. Inside *rías* there are the most important marine aquaculture cultivation of mussels in Europe. Mussels are cultivate in rafts hanging onto ropes, from seed to commercial size. The number of mussels rafts in Galicia is around 3,537 share inside the *rías*. It is an intensive culture regime. This region is also well known for its growing turbot farming industry, in an intensive culture regime using mainly land-based tanks and raceways, open and re-circulation but also sea cages. Most turbot farms are located in exposed areas, rocky shores and cliffs frequently near Natura 2000 areas such as the Corrubedo dune system and the Costa da Morte. Oysters are cultivated in the intertidal zone on racks and /or hanging onto rafts, in intensive regime. Other shellfish such cockles and clams are semi-intensively cultivated in the intertidal zone in Government concessions. A reduced production of sea bream in sea cages or land facilities, and on an experimental level, sole and pollack and octopus in sea cages.

Asturias region is a coastline with sandy beaches, cliffs, estuaries and coastal dunes, some of them included in Natura 2000 as LIC. Estuaries are used for marine aquaculture, especially for oyster cultivation on racks and the bottom culture of clams in the intertidal zone in the estuary of Eo river. Turbot is cultivated intensively in land-based tanks. Marine aquaculture in this region is still a very small scale.

Cantabria marine aquaculture is represented by turbot, sea bass and sea bream juveniles in intensive land-based tanks in the Tinamenor Bay and bivalve seed production using earth nursery ponds, provoking blooms of phytoplankton in salt marshes. In this region it is the best preserved coastal wetland of the North of Spain, included in Natural 2000 as LIC (SAC).

In the Basque Country, an important wetland comprising salt marches and estuaries in the mouth of the Bidasoa river is the only Spanish river holding salmon population. Marine aquaculture is reduced to cultivation in land-based tanks.

The Atlantic coastline of Andalusia represents the major part of the marine aquaculture production of this region. In the Cadiz Bay, an important wetland with sand-flats is exposed during low tide and there is extensive culture of different fish species, including polyculture. Traditional methods use natural fry grown in lagoons and swamps. Sea bass and sea bream are the main species cultivated in old salt lagoons and in sea cages. Molluscs are cultivated in the intertidal zone in concessions. Swamps, salt marches and intertidal zones are the main sites for semi-intensive cultivation system. In the Gulf of Cadiz there are mussels cultivated with rafts and long lines.

This region includes two large Natura 2000 areas - Cadiz Bay is considered an important wetland and the National Park of Doñana is the major southernmost refuge for wintering birds in Europe.

The marine aquaculture in the Canary Island is mainly concentrated in Tenerife and Gran Canaria. Offshore marine fish-cage farming cultivates sea bass and sea bream. The Canary Island are part of the Macaronesian region, together with Madeira and Azores archipelagos. The most of coastal protected sites include Natura 2000 area and are located in exposed zones, open to winds and marine currents.

The marine aquaculture in Spain is quite diverse with traditional shellfish exploitations where the most aquaculture is in extensive or semi-extensive systems in the intertidal zone using old salt works and lagoons. There is also sophisticated raft mussel cultivation industry.

As regards marine fish farming for sea bass and sea bream, production techniques are very diverse, ranging from extensive to highly intensive systems, involving earth ponds, floating cages, raceways or tanks. Cages units are the most common, used in lagoons, sheltered bays or semi-exposed and offshore conditions. Turbot aquaculture is found in land-based hatcheries and on-growing units.

Traditional bottom culture for cockles and clams is sited on large sand-flats and estuaries exposed at the low tide with a soft substrate, quite protected against strong seas and with a low level of predators. Mussels rafts need to be located in protected bays with well flushed, good quality water. Rafts inside the *rías* have a single anchorage that turns with the tides, whilst offshore rafts have two anchor points. Rafts need to be sufficiently deep to be able to hang ropes of 12 metres length, 6-8 metres from the bottom to avoid as much as possible predators. Intensive finfish cultivation in land-based facilities need to be located in coastal areas in reach of good quality sea water. Cages offshore or in sheltered waters need to be placed permitting net clearance and avoiding tourist beaches.

Marine aquaculture in Spain is socio-economically significant since it has generated a lot of job posts and contributing to mitigate the reduction of capture fisheries job opportunities. In Galicia the marine aquaculture has generated around 25,000 job posts (direct around 13,000) and annual turnover about € 200 million, with mussel cultivation accounting for more than 80%. In general terms the aquaculture activity in the Spanish coastline has provided around 28,000 job posts (direct and indirect) and annual turnover around € 225,000,000.

Spanish aquaculture in general accounts for 3% of the world production and 25% of the European production in weight. The total value of aquaculture of fish species sold for consumption in 2004 equals 131.6 million euros. Mariculture fish producers employed directly a total of 1,564 workers in 2004.

France (Atlantic)

Regional production patterns: marine aquaculture in **France** on the Atlantic coastline is essentially divided in shellfish production (mainly mussels and oysters) and fish production (sea bass, sea bream, turbot, etc). In both northern and southern Brittany there are shallow bays, estuaries and large sand-flats and dunes. This coastline holds intensive aquaculture activity, using the shallow bays and estuaries to exploit mussels and oysters as they are productive areas with strong spring tides. Oysters and mussels represent the most important marine aquaculture production in this region, using traditional but intensified cultivation systems. Traditional oyster cultivation is in plastic bags on racks at the intertidal zone (Bay of Morlaix, Rade de Brest et de Concarneau, Côte d´Armor and Bay of Quiberon) and on the sea bed in deep water (*eau profonde)* at Bay of Quiberon inside the Gulf of Morbihan (a Ramsar site), using trawlers for harvesting. Mussels are traditional cultivated on *bouchot* and on the sea bed and recently there are a few examples of innovation using long line systems. Mussels and oysters are cultivated semi-intensively adjacent to Natura 2000 habitats such as reefs, estuaries and coastal dunes with a high biodiversity in benthic fauna and flora. Other bivalves are produced in semi-intensive regimes in the intertidal zone, subject to seasonal bans and restrictive licensing. Fish production is carried out in an intensive regime, mostly in land using tanks and ponds, pumping seawater. Turbot fry are produced in tank recirculation systems. The production of seaweed (brown and red seaweed and micro-algae) takes place on a very reduced scale or experimental level but an important natural harvesting is carried out in this region with around 70,000 t per year.

In the Pays de la Loire region the most important aquaculture activity is intertidal semi-intensive oyster cultivation using the traditional rack method as well as the seabed. Mussels are cultivated on *bouchot*, a lower intensity method in comparison to other regions. Other shellfish are cultivated on the sea bed in the intertidal zone in a semi-intensive regime. These activities take place on the sand-flats and estuaries where there is a good water renewal due the large tides. *Les marais salants de Guérande* is classed as a Ramsar site. Also there is some fish culture in land–based facilities, at Noirmoutier Island, in tanks and /or pond in the *marais sales* (seagrass meadows) using pump and recirculation systems, using a supply of subterranean saline water (a characteristic of this region) for fish and seaweed culture. The most important turbot fry producer of Europe is located in this region.

The Poitou-Charantes region has important oyster production cultivated on racks in the intertidal zone. These oysters before to go to the market are placed in ponds (*claires)* for a special treatment "*affinage*" to improve the quality of oysters. Oysters can grow in the *marais sales* (sea grass meadows). Mussels are cultivated in concessions of *bouchot* and long lines of floating plastic buoys in deep sea water. The full cycle production for sea bass, hatcheries for sea bream and a hatcheries/nurseries for oysters are land-based but the growth of turbot carried out in the sea grass meadows. These cultivation areas in the Pertuis Charentais includes Natura 2000 designated areas, remarkable for the quality of the marine environment and the high productivity. The sea-grass meadows important area for wild birds and fish nursery.

The Aquitaine region is an important production of marine aquaculture. Oyster production is located at the Bassin d'Arcachon, the most important area for natural production of seed oysters in Europe. It is a large marine bay of variable salinity with rare species and key refuge for wintering birds, and included in the Natura 2000 network. Oyster cultivation is in the intertidal zone on racks in intensive regime. The Bassin d'Arcachon is a semi-enclosed area, subject to the daily tides fluctuation, and is a very productive place where molluscs develop quick and is favourable for natural oyster seed production. In the South of the Bassin d'Arcachon there is the Pyla dune, a 2 km long sand dune of 100 m high. Turbot is cultivated in tanks and ponds are located at the Bassin Adour-Garonne a well known resort station at the French Basque Country. At the Point du Médoc there is a pond farm producing prawns, a new species for the aquaculture in France.

The Basse-Normandie region includes important Natura 2000 areas, including the Mont Saint-Michel Bay (also a Ramsar site) that act as a refuge for birds in winter. Oysters and mussels are produced here using the traditional method in France of *racks* and *bouchots* in the intertidal zone. This region is one of the most important oyster and mussels producers in France. The large spring tide range in this region requires that mussels and oysters are placed far from land. Culture sites are accessible at low tides during spring tides. In this region aquaculture boats are supplied with wheels to permit to cover the distance from sea to land to the site during the low tides.

Marine aquaculture in the Pas de Calais region is represented by an important production of sea bass and sea bream, juveniles and adults in tanks and ponds using water from the nuclear power station of Gravelines. Limited mussel production using *bouchot* culture and bottom culture is practiced in the intertidal zone of the sand-flats exposed during low tides.

Siting of shellfish culture in France uses Government concessions on large sand-flats, exposed at the low tide, on the zone where the sediment is sufficiently firm to support equipment and relatively well protected from the strong swell. Sea bass and sea bream culture in the Atlantic coastline uses the higher sea water temperatures of nuclear power station effluents to achieve a high production. Intensive fish production in recirculation system needs develop sophisticated technology to control the water quality. Pond culture must have a good clay content to retain water or to be covered by concrete / plastic: floodgates and/or pumping systems can be require.

In France there are more than 4,150 marine aquaculture companies which around 3,720 are specialised in the shellfish cultivation. The marine aquaculture are installed on the Government concessions, around 100,000 km².

The aquaculture in France is socio-economic important because it has generated around 23,944 job posts, full and part time. Most of this jobs are generated by the shellfish cultivation – the annual turnover overtakes €516 million with more than 86% coming from shellfish farming.

United Kingdom

Regional production patterns: coastal aquaculture in the **UK** is largely centred around the salmon farming operations off the North West coast of ***Scotland***, including Strathclyde, Argyll, Sutherland and the Hebrides, Orkney and Shetlands. These cage farming operations tend to occur in the sea lochs, where possible sheltered from the prevailing south-westerly winds. In most cases the prevalent currents or tidal movements are used to ensure adequate flushing of cage units, although sites are often rotated and sites fallowed to improve productivity and allow sites to recover. These farms are often important employers in remote rural regions, yet many are also placed in areas of considerable natural beauty and conservation interest. As recognised by the recent 'Locational Guidance for Aquaculture' (in Scotland), the presence of European sites or other 'very sensitive areas' is an important screening consideration for new or expanded fish farming operations. The main conservation interests of SACs in these areas are common or grey seals, rocky reef areas, shallow inlets or lagoons. The opportunity for development of new finfish sites is expected to be limited in Scotland, unless offshore or exposed locations become attractive. Modification and consolidation of existing sites, either by a change of species or change in equipment specification, or relocation to alternative sites is likely to be the way forward. With increasing competition from Norway and South America, there is a trend towards diversifying into other finfish species such as halibut and cod, using established technology and experience in cage culture. In ***England*** and ***Wales*** most coastal aquaculture is in the form of bivalve production. The largest bivalve producing area in the UK is in the Menai Straits in north Wales and other key production areas are the south west, south Wales and the Wash on the east coast with increasing interest also being shown in Kent and Essex. Whilst mussel rafts are used in Scotland and Wales, other areas tend to use shallow or intertidal bottom culture on soft substrates that are often within or adjacent to SPAs. Scottish bivalve production mainly uses rafts where interactions with Eider ducks are a considerable concern.

Ireland

Salmon production in **Ireland** follows a similar pattern to Scotland, with most fish being farmed in sea cages in sheltered sea loughs in Donegal to the north-west, Galway to the east and Counties Cork and Kerry to the south east. Production in Donegal is mostly based around the bottom culture of mussels (around 24,000 t in 2003) as well as salmon, rope mussel culture and the rearing of Pacific Oysters. In the east, Counties Galway and Mayo produces a large proportion of Ireland's salmon (6,300 t and 1,300 t respectively) as well as Pacific oysters and rope-grown mussels. Down in the south-west, Counties Kerry and Cork produce bottom and rope-grown mussels respectively , together with Pacific oysters and salmon.

Denmark

A ban on establishing and extending marine fish farms in **Denmark**, issued in 1996 by the Danish Environmental Protection Agency, was lifted in 2001. An *ad hoc* advisory board was established with similar purposes for marine fish farming in Denmark. One of the recommendations (2003) was that off-shore cages should be located in areas with optimum conditions for diluting and spreading emissions from the cages. Aquaculture production in Denmark is mainly concentrated on rainbow trout (*Oncorhynchus mykiss*), farmed in sea cages or land-based facilities, although there is some mussel and oyster culture. This is only taking place on a very small scale or experimental level, although relaying of sub-sized mussels from the fishery in Limfjorden has taken place since 1990. With the establishment of the Danish Shellfish Centre it is the aim to increase mussel farming in Danish waters.

Netherlands and Belgium

Mariculture in the **Netherlands** is dominated by shellfish, in particular mussels, clams and oysters. The most important producers are the region of Zeeland (mussels and oysters) and the Waddenzee area which covers the coastlines of the regions Nord Holland (mussels), Friesland and Groningen (clams). Marine fish species are limited to flatfish which are produced in small quantities in Zeeland (125 t of Turbot in 2004) and Nord Holland (30 t of Sole in 2004).

The majority of Belgian mussel culture is based in the Province of West-Vlaanderen on the border with France. The majority of production in the Netherlands is done with bottom cultivation, however a small but growing segment is now done as hanging, or mid water culture on long lines. Grow-out time is just over two years with seed collected on the intertidal flats. After collection the seed is transported to specifically marked lease sites. 30 m boats that both broadcast and dredge are very mechanized in such that most operate with only three people on board. The mussel season for bottom cultivation runs from the end of July through to April. Typically with in the two year + grow-out cycle the animals are taken up and redeployed in different areas 2-3 times. Mid-water long line culture is relatively new in the Netherlands, there is however a newly formed long line association and the method of husbandry is growing. Double long lines 600-700 meters long are chained to the shore, 20 meter socks with 8-10 mm seed socked at 1 kg per meter yield between 7-10 kg per meter in 12-14 months, half the time of bottom culture.

The industry is not without its problems however, in that total production in recent years has been reduced to approximately 70,000 tonnes. The primary cause of this has been lack of seed, normally collected from intertidal flats. Access to seed has been restricted over concerns regarding the impact of juvenile collection on wild bird populations.

2.2.2 Baltic Sea

The Baltic is a shallow, semi-enclosed sea, strongly influenced by human-induced eutrophication, river runoff and a lack of rapid exchange with the adjacent ocean. It is essentially a fjord that is 1,500 kilometres long with an average width of 230 kilometres, divided into basins and includes the Gulf of Finland and Gulf of Bothnia. Large-scale meteorological conditions determine long-term fluctuations of salinity and temperature in the deep and bottom waters. The Baltic Sea receives fresh water from river runoff, with a maximum in May and a minimum in January or February. Its brackish waters contain a mixture of marine and freshwater species. The coastal areas serve as spawning, nursery and feeding areas for several species of fish. The Baltic Sea LME is considered a Class I, highly productive (>300 g C/m^2.yr) ecosystem based on SeaWiFS global primary productivity estimates.

Germany does not have a well developed marine aquaculture sector. Some developments in net cage culture in former East Germany were stopped after reunification because of environmental concerns. Instead, some effort was made to develop technical systems with re-circulating water both for fresh and saltwater species. For what concerns marine fish species in particular, there seems to be only one company (Ecomares) producing turbot at commercial level with the use of closed re-circulating systems. For confidentiality reasons the company does not provide information on the quantities produced. Eel production, mainly practiced in freshwater, represents a very small portion of production (4% in value). There is no record of marine shellfish culture.

Marine aquaculture in **Finland** is currently almost entirely (98%) based on the sea cage farming (1.095 million m^3 culture area) of rainbow trout in the south west off Aland and Varsinais Suomi as well as some (18,000 m^3) pond and tank (2,000 m^3) culture. Fish farming plays a minor role in coastal the economy (with the exception of Aland) and is under considerable pressure from both recreational costal users as well as the countries stringent water laws. Throughout the 1990s, in accordance with the governments water protection program, the water courts have allocated the fish farming industry lower production limits. Thus, in order to survive, the fish farming industry is now forced to develop new fish farming strategies (Eurofish, 2000) and many of the fish farming companies are moving to Sweden. Combined with the competition from Norwegian salmon production and imports, any future development of the aquaculture industry is likely to be dependent on diversifying away from rainbow trout. Marine aquaculture in **Sweden** comprises blue mussel production (1,425 tonnes) and cage farming of rainbow trout (3,000 tonnes, which includes some fresh water production of this species), but production has declined since the late 1990's. A common problem for marine finfish farms in the Baltic are the high levels of Persistent Organic Pollutants (POPS) such as PCBs, dioxins and Polybrominated Diphenyl Ethers (PBDEs) in forage fish from the industrialised waters of the Baltic and coastal waters that means feeds are usually sourced from outside the region.

2.2.3 Mediterranean

The Mediterranean is a semi-enclosed sea. It has a narrow continental shelf and highest levels of productivity occur along the coasts, near major cities, and at river estuaries. Overall, the Mediterranean Sea LME is considered a Class III, low (<150 g C/m2-yr) productivity ecosystem, based on SeaWiFS global primary productivity estimates.

Spain (Mediterranean)

Regional production patterns: The largest part of the Spanish Mediterranean production is concentrated in the south east. The regions of Andalucia and Comunidad Valenciana account for almost 50% of the Mediterranean production on their own (Andalucia with 31% and Comunidad Valenciana with 22% in 2003), although it must be noted that Andalucia hosts aquaculture activities dedicated to both Atlantic and Mediterranean species because of its particular geographical position. The region Murcia also accounts for a large part of Mediterranean production (27%) but this has to be attributed almost exclusively to the capture-based aquaculture of tuna (3620 t in 2003).

Sea bream (*Sparus aurata*) accounts for approximately 65% of the production in Andalucia and 80% in Comunidad Valenciana. The latter can also claim a consistent production of eel (*Anguilla anguilla*), accounting for 76% of the national production in 2003. Sea bass (*Dicentrarchus labrax*), also produced in these regions, as in a few other regions of the south east, is the only other fish species making up a relevant part of the national production in weight, with the mentioned exception of tuna.

Regarding shellfish, the region of Catalonia is the only producer worth of notice in the Mediterranean, with 428 t of oysters and 1,493 t of mussels and 95 t of clams in 2003. In fact, most of the shellfish production is hosted on the Atlantic coast.

In the Mediterranean area sea bass and bream are cultivated in sea cages although each region is currently specialising in different aquaculture systems. Mussels are cultured with the use of bottom longlines. Worth of notice is the experimental cultivation of new species amongst which Octopus (*Octopus vulgaris*) and the Common dentex (*Dentex dentex*). In 2003-2004 Spain has started two National Plans for the aquaculture sector which concern the environment directly :

- Environmental impact of sea cages
- Minimisation, treatment and valorisation of aquaculture residues

In 2005 another Plan called "*Mitigation of the environmental impact generated by aquaculture activities*" has been proposed showing that environmental aspects are of great concern for Spanish aquaculture.

Italy

Regional production patterns: In general, aquaculture activities in Italy are concentrated in the northern Regions (NUTS 2) accounting for 68% of the producers in 2003. This reflects mainly the high concentration of clams (*Tapes philippinarum*) and mussels (*Mytilus galloprovincialis*) producers in the northern Adriatic Sea (concentrated in the Po Delta dominating the coastal areas of the Regions Veneto and Emilia-Romagna). Fish production has increased by 8% in quantity compared to 2002. The region Sardinia in itself accounts for 25% of the Italian fish production with 4,000 tonnes in 2003. The most common cultured fish species are bass (*Dicentrarchus labrax*) and bream (*Sparus aurata*) accounting for 94% of total marine fish production. The production of corb (*Sciaena cirrhosa*) has increased by 34% compared to 2002 thanks to the now acquired artificial reproduction technology which guarantees good quantities of juveniles for the production facilities.

Siting: For what concerns shellfish aquaculture, mussels dominate with 74% of producers dedicated to the culture of this species at sea or, less frequently, in lagoons. Clams follow with 25% of producers. Oysters (*Ostrea edulis*) production is very limited and mainly confined to the lagoon areas of Orbetello (western Sardinia). The region Liguria hosts 1/3 of the Mussels production facilities although the highest production (15,000 tonnes) originates from the region Emilia-Romagna. Crustaceans include only Paeneid species and are limited to 12 tonnes produced in Sardegna and, to a lesser extent, Veneto.

Production systems: In general, tanks in cement or fibreglass remain the main production system for marine fish species, followed in decreasing order of importance by ponds, sea cages and lagoons. Cement tanks are used mainly in the Region Puglia with a mean volume of 4,400 metric cubes per production unit. Ponds are mainly diffused in the Regions Sardegna, Veneto, Toscana and Friuli Venezia-Giulia, all areas where aquaculture in lagoons has a long tradition. The use of ponds or tanks for marine fish production is slowly decreasing as sea cages become more common. Sicily dominates with 33% of facilities using cages for a total mean volume of 110,000 cubic meters per facility. Mussels are cultured on long lines in shallow coastal areas, while clams are trawled with the use of suction pumps (turbo-soffianti). The productive surface of mussels has increased by 56% compared to 2002 distributed mainly in the Regions Emilia-Romagna (32%), Veneto (22%) and Puglia (20%). For crustaceans, ponds and tanks in cement or plastic are the main production systems.

Shellfish culture has the most relevant siting requirements along the Italian coastline as they require considerable surface areas and specific environmental conditions. Clams require shallow bottoms with fine sediments (mud) that are found in abundance in the northern Adriatic Sea (Po Delta area). Mussels require waters rich in nutrients which are also found in the northern Adriatic as the waters of the Po river provide for large quantities of organic sediments. Alternatively mussels are cultivated in brackish lagoon areas. As most fish species are cultured in ponds or tanks there are no specific siting requirements except for access to sea water to be pumped in the tanks.

Environmental issues: Offshore sea cages are particularly promising in Italy, and the southern regions in particular, as they do not occupy areas with scarcity of space and conflicting economic interests (e.g. tourism). In addition, this production system facilitates dispersion of sediments, stabilises chemical parameters and improvement of water quality with obvious environmental advantages.

Socio-economic importance: Generally, the Italian production from capture fisheries and aquaculture has been constantly decreasing for more then a decade. In 2003 production compared to the previous year shows a decrease by 10%, while going back to 1995 (last year witnessing an increase in production) the total decrease in production sums up to 36%.

The negative performance over the last year has to be attributed mainly to aquaculture production which has decreased by 27% in 2003 after almost 20 years of regular growth. This reduction is explained by the harsh climatic conditions (droughts and extreme heat) experienced throughout Europe in the summer of 2003 which caused serious difficulties to mussels and Clams production. On average the overall value of aquaculture products in 2003 was 442 million euros (-14% compared to 2002).

Over the last years, the market maturity in Europe and the increasing competition has forced Italian aquaculture producers to improve their techniques with a reduction in production costs and, as a consequence, lower cost of the end product on the market. In addition, offer has been greatly diversified with the development of new products, processing and packaging systems.

In 2003 the aquaculture sector employed a total of 7,764 workers. Approximately 30% of these are employed in mussels production in the Region Veneto followed by 24% in the Region Lombardia (mainly freshwater fish production). In particular, marine fish cultures employed 954 workers and shellfish cultures (bivalves and crustaceans) 3,753 workers. Approximately 70% of the workers have a regular contract while the rest are seasonal workers mainly employed in mussel farms for short periods.

France (Mediterranean)

Regional production patterns: Only three regions of **France** face the Mediterranean : Languedoc-Roussillion, Provence Alpes-Cote d'Azur and Corsica. The first of these regions, bordering Spain, accounts for almost 80% of French Mediterranean mariculture production.

Bass (*Dicentrarchus labrax*) and bream (*Sparus aurata*) represent between 90 and 100 % of marine fish production, but fishes in general accounts for only 10% of mariculture production. Shellfish culture, on the other hand, accounts for the remaining 90%. Cultured species are oysters (*Ostrea edulis* and *Crassostrea gigas*), Mussels (*Mytilus galloprovincialis* and *edulis*) and, to a lesser extent, clams (*Cardium edule*, *Ruditapes decussatus* and *Tapes philippinarum*). Languedoc-Roussillion hosts 97% of the shellfish production, most of which is located in the lagoon of Thau (Etang de Thau) or at sea in close by areas. In any case, the Mediterranean shellfish production remains very limited compared to the Atlantic coast.

The production systems used for marine fish species are generally sea cages or closed re-circulating systems (mainly used in the region Languedoc-Roussillion). Oysters are typically cultured in suspension on floating long lines or on fixed tables (mainly used in the Etang de Thau). On the Mediterranean coast of France mussels are typically cultured on long lines.

In 2002 France recorded 4150 aquaculture producers (marine and freshwater) of which 3,720 were specialised in shellfish culture. Collectively, the value of the production can be estimated in 533 million euros, more then half of which (371 million) to be attributed to shellfish culture. In fact, France is the first producer of cultured shellfish in the EU, with oysters (*Ostrea edulis* and *Crassostrea gigas*) and Mussels (*Mytilus galloprovincialis* and *edulis*) accounting for most of the production.

More then 21,500 people work in the shellfish culture sector, of which 7,000 are full time employees.

2.2.4 Eastern Mediterranean

Regional production patterns: marine finfish farming in the Eastern Mediterranean takes place mainly in **Greece**, using its extended coastline as well as in the west coast of **Turkey** and the South coast of **Cyprus**. The species produced are mainly sea bream and sea bass (*Sparus aurata* and *Dicentrarchus labrax*) although there have recently been successful attempts to rear other species such as *Puntazzo puntazzo, Pagellus erythrinus, Diplodus sargus, Pagrus pagrus, Dentex dentex* etc. (Divanach 2003). During the last five years there has been increasing interest in tuna farming, which in fact is ongrowing young individuals captured from the wild. Tuna farms are very few at the moment although they are currently considered among the most profitable investments. In Greece, fish farms are distributed in all parts of the country both in the Aegean and the Ionian Sea, along the coast of the mainland but also in the islands. The extended coastline (almost 17,000 km) provides many locations suitable for aquaculture even in highly developed areas in terms of tourism facilities. Mussel farms on the other hand are mainly found in Northern Greece since the oligotrophic conditions of the South Aegean are not suitable for providing enough phytoplankton to filter feeders. In Cyprus, the aquaculture (fish farming) industry is located on the south coast of the island, at fairly deep sites (>35m bottom depth) and at distance more than 1 km offshore to minimise negative interactions with the tourism industry and to avoid effects on seagrass meadows. In Turkey most of the farms are located at the Aegean coast, at fairly shallow depth.

Production is normally carried out in open coastal bays relatively well protected from wave action but with adequate water renewal to ensure dispersion of metabolic wastes and hence high water quality. The production systems are almost invariably fish cages with a few exceptions (much less than 5% of the production) where traditional extensive systems are used in lagoons in Central and Western Greece. The fish cages used are of various types and sizes and occasionally various types and sizes can be found at a site used by a single company. Other sources of variability include feeding systems (hand feeding or automated systems), depth of the locations used (from 10 to 100m) and distance from the coastline (from 10m to more than 1 km).

In most Mediterranean countries the **tuna** farming season extends for about 6-7 months, starting typically in June. It is estimated that 225,000 tonnes of feed fish were used on tuna fattening farms in the Mediterranean over 2004. A large percentage of the fish feed utilized in the Mediterranean tuna farming industry is imported frozen from outside the region (over 95% of total baitfish in the case of Turkey; Lovatelli, 2003). The precise specific composition of feed fish is not known in most of cases, but Lovatelli lists the small pelagic species used as including sardine (*Sardina pilchardus*), round sardinella (*Sardinella aurita*), herring (*Clupea* spp.), mackerel (*Scomber scomber*) and horse mackerel (*Trachurus* spp.). These fish originate mostly from the North Sea/Baltic region and the West African upwelling system. WWF have noted that the use of non-compounded fish feeds for tuna has had a number of undesirable impacts such as increasing the fishing pressure for species that were not previously fished commercially, such as the round sardinella in the western Mediterranean, with possible consequences for one of its main predators, the common dolphin. In addition, they raise the possibility of transmitting viruses from non-endemic feed fish to local wild fish populations, as has been experienced in Australian waters (WWF, 2005).

Particular siting requirements: The siting requirements vary enormously between countries. Although there is a standard requirement for an Environmental Impact Study (EIS), there is little common consideration of regulatory issues among Mediterranean countries. A proposal for a common site selection protocol (PAP/RAC 1996) has not been uniformly adopted by Mediterranean countries. In Greece, the leading country in terms of production, the administration imposes a series of procedures for the approval of a farming site (Papoutsoglou 2000) but there are not precise requirements for data to be included in the EIS nor any standard monitoring programmes used. A recent change in the regulatory framework provides for the establishment of Areas for Organised Development of Aquaculture (AODA) that will be regularly monitored and any development will be considered in basin-wide scale. In Cyprus, there is a more strict regulation imposing minimal depth and distance from the coast and the regulatory framework (called strategy for the development of Aquaculture) is periodically revised by external panels of experts. All farms are regularly monitored during the last few years using the recommendations of GESAMP 1996.

Socio-economic importance of aquaculture: Fish farming is an exporting industry for most Mediterranean countries. In addition fish farming provides employment throughout the year in remote areas where there are very few other employment alternatives. In some small islands fish farming industry and the associated economic activities (hatcheries etc) are among the largest sources of employment in the private sector. Economic studies on these issues (Katranidis 2001) have shown that social acceptability of aquaculture varies among areas depending on the size of the industry, the side effects on local economies, the time elapsed after the investment etc. However, the negative effects (aesthetic degradation of the scenery) have often caused conflicts with other uses of the coastal zone and particularly with land-owners in the vicinity of an aquaculture site which have yielded a large number of court cases.

Known environmental issues: several characteristics of the Mediterranean determine the fate of aquaculture wastes:

- High temperature (annual minimum of 12ºC, reaching up to 25ºC during summer) induces high metabolic rates of microbial communities.
- Microtidal regime (tidal range is typically less than 50 cm) reducing the potential for dilution and dispersion of solute and particulate wastes particularly in enclosed bays where wind-driven currents are relatively weak.
- Oligotrophy: low nutrient content, low primary production, and low phytoplankton biomass are typical for most Mediterranean marine ecosystems particularly in the Eastern Basin. Low phytoplankton biomass induces high transparency of the water and light penetration deeper in the water column thus allowing for photosynthesis to a greater depth.
- Primary production is considered to be phosphorus limited at least for part of the year, as opposed to nitrogen limitation in the Atlantic and in most of the world's oceans. In this context, eutrophication could be expected only when phosphate is released in adequate quantities.
- The biotic component of the ecosystem i.e. the fauna and flora are highly diverse particularly in the coastal zone with a large proportion of endemic species as a result of the dynamic geological past of the Mediterranean, and typically with low abundance and biomass as a result of the prevailing oligotrophic conditions.

During the last decade there has been considerable effort invested in research on environmental impacts of fish farming in the Mediterranean. Both national and EU funded projects have addressed complementary aspects of this issue in a variety of different conditions and sites, resulting in substantial gain in the understanding of the relevant processes.

3 ENVIRONMENTALLY SENSITIVE AREAS IN EUROPE

3.1 DEFINING ENVIRONMENTALLY SENSITIVE AREAS

The European Environment Agency (EEA) defines environmentally sensitive areas as:

'*Areas of a country where special measures may be given to protect the natural habitats which present a high level of vulnerability*'. *(http://glossary.eea.eu.int/EEAGlossary/search_html).*

This term is all embracing and relates to a wide cross section of geographical locations and ecosystems and for a wide variety of natural and human operations. In addition, a single geographical area can be sensitive and protected through a number of different statutory and non-statutory management processes. For example, environmentally sensitive areas can include subterranean groundwater protection zones, and nitrate sensitive zones, surface water protection measures and biodiversity protection measures. Furthermore, in other areas measures are introduced to encourage more sustainable management practices such as through Common Agricultural Policy or Common Fisheries Reform through environmentally sensitive area payments (ESA) or restricting fishing activity (fish migration or spawning).

The following section reviews the likely impacts of aquaculture on nature conservation and a brief description of each of the designations and how (if at all) the designation affects aquaculture activities. The major statutory designated areas of special conservation interest are focused upon. This ensures that the most sensitive and valued habitats across Europe are fully reflected.

The following major areas of conservation and landscape interest are reviewed:

- Biogenetic reserves;
- Biosphere reserves;
- Marine Protected Areas;
- Ramsar Sites;
- World /Heritage Sites;
- Natura 2000 sites (Special Protected Areas (SPA) and Special Areas of Conservation (SAC);
- Specially Protected Areas of Mediterranean Importance (SPAMI).

A series of maps are produced in **Appendix D** to identify the geographic spatial distribution of the Natura 2000 network. They are also replicated at a larger scale in Appendixes E and F for key finfish and shellfish production areas respectively. Here other nature conservation designations e.g. Barcelona Convention SPA, CoE Biogenetic Reserves, CoE EuroDiploma, Helsinki Convention, Ramsar Sites, UNESCO BioSphere Reserves and World Heritage Sites) are also shown.

3.2 ENVIRONMENTALLY SENSITIVE SITES COVERED BY THIS PROJECT

3.2.1 Biogenetic Reserves

Biogenetic Reserves aim to conserve European flora, fauna and natural areas especially heathlands and dry grasslands that although common in one country may be scarce in another. In this way a store of genetic material – the genes of plants and animals – is kept for the future, hence the term biogenetic.

The biogenetic reserves[5] are designated for their biodiversity, the importance of minimising the impacts of coastal aquaculture to these sensitive sites will depend upon the habitats for which the individual sites are designated. The most sensitive habitats will be coastal and marine though the impacts will depend upon the location, intensity and management activities which are taking place. The reserves do make reference to economic and human development and therefore aquaculture activities may not be adversely affected.

3.2.2 Biosphere Reserves

Biosphere Reserves are areas of terrestrial and coastal ecosystems promoting solutions to reconcile the conservation of biodiversity with its sustainable use. They are internationally recognized, nominated by national governments and remain under sovereign jurisdiction of the states where they are located. Biosphere reserves serve in some ways as 'living laboratories' for testing out and demonstrating integrated management of land, water and biodiversity. Each biosphere reserve is intended to fulfil three basic functions, which are complementary and mutually reinforcing (http://www.unesco.org/mab/nutshell.htm):

- A conservation function - to contribute to the conservation of landscapes, ecosystems, species and genetic variation;
- A development function - to foster economic and human development which is socio-culturally and ecologically sustainable;
- A logistic function - to provide support for research, monitoring, education and information exchange related to local, national and global issues of conservation and development.

Biosphere Reserves are not covered by an international convention but for an area to be designated, it must simply meet a set of 3 criteria outlined above[6]. The jurisdiction is the responsibility of the nation state and therefore the process and management implications will vary from state to state. Some countries have enacted legislation specifically to establish biosphere reserves. However, in many cases, advantage is taken of the existence of areas already protected under national law to establish biosphere reserves.

A wide variety of habitats are present within these biosphere reserves ranging from woodlands or scrubs to wetlands. In particular, coastal and marine habitats such as dune systems, salt marshes and tidal flats are present within some biosphere reserves within Europe. The presence of the designation is likely to result in the need for a greater level of understanding of the impacts of the activity (e.g. aquaculture) with a greater emphasis on impact minimisation, environmental enhancement and sustainable development. Landscape impacts (e.g. aquaculture development) interestingly are unlikely to affect site integrity.

[5] http://www.ccw.gov.uk/ccwdigitaldownload/protectedsites.html#Biogenetic%20Reserves

[6] http://www.unesco.org/mab/nutshell.htm

3.2.3 Ramsar Sites

The Ramsar Convention (or Wetlands Convention) was adopted in Ramsar, Iran in February 1971 and entered into force in December 1975. The Convention is an intergovernmental treaty which covers all aspects of wetland conservation and wise use. The Convention has three main 'pillars' of activity: the designation of wetlands of international importance as Ramsar sites; the promotion of the wise-use of all wetlands in the territory of each country; and international co-operation with other countries to further the wise-use of wetlands and their resources (http://www.jncc.gov.uk/page-1369). Each Contracting Party is invited to designate a national governmental agency to act as the Administrative Authority of the Convention in the country.

Wetlands are among the world's most productive environments. They are cradles of biological diversity, providing the water and primary productivity upon which large numbers of plant and animal species depend for survival. They are also important locations of plant genetic diversity and support large numbers of bird, mammal, reptile, amphibian, fish and invertebrate species (http://www.ramsar.org/about/about_infopack_1e.htm). Wetlands provide tremendous economic benefits through their role in supporting fisheries, agriculture and tourism, and through much of the world they have a crucial role as a source of clean water for dependant human populations. Unfortunately they are also among the world's most threatened ecosystems, owing mainly to continued drainage, pollution, over-exploitation or other unsustainable uses of their resources.

Aquaculture is likely to have an impact on Ramsar sites depending on the location of the wetland and its exposure to the activity, with implications on biodiversity as well as the economic activities they support. Article 3.1 of the Convention would need to be taken into account when planning aquaculture activities to balance conservation and human needs.

3.2.4 Marine Protected Areas

These are intended to contribute both to protection of threatened species and habitats and to the conservation of areas which best represent the range of species, habitats and ecological processes in the OSPAR area (The Convention for the Protection of the Marine Environment of the North-East Atlantic). At Sintra, Portugal, in 1998 the Ministerial Meeting of the OSPAR Commission adopted a new Annex V "On the Protection and Conservation of the Ecosystems and Biological Diversity of the Maritime Area" and an accompanying OSPAR Strategy. The objective of the Commission is to take the necessary measures to protect and conserve the ecosystems and the biological diversity of the maritime area which are, or could be, affected as a result of human activities, and to restore, where practicable, marine areas which have been adversely affected (http://www.ospar.org/eng/html/welcome.html). The Commission will, *inter alia*, promote the establishment of a network of marine protected areas ("MPAs") to ensure the sustainable use, protection, and conservation of marine biological diversity and ecosystems – the OSPAR Network of Marine Protected Areas ("the OSPAR Network").

The components of the OSPAR Network will, individually and collectively, aim to:

- protect, conserve and restore species, habitats and ecological processes which are adversely affected as a result of human activities;
- prevent degradation of and damage to species, habitats and ecological processes, following the precautionary principle; and
- protect and conserve areas that best represent the range of species, habitats and ecological processes in the OSPAR maritime area.

An area qualifies for selection as an MPA if it meets several but not necessarily all of the following criteria:

- Threatened or declining species and habitats/biotopes. The area is important for species, habitats/biotopes and ecological processes that appear to be under immediate threat or subject to rapid decline as identified by the ongoing OSPAR (Texel-Faial) selection process.
- Important species and habitats/biotopes. The area is important for other species and habitats/biotopes as identified by the ongoing OSPAR (Texel-Faial) selection process.
- Ecological significance. The area has:
    - a high proportion of a habitat/biotope type or a biogeographic population of a species at any stage in its life cycle;
    - important feeding, breeding, moulting, wintering or resting areas;
    - important nursery, juvenile or spawning areas; or
    - a high natural biological productivity of the species or features being represented.
- High natural biological diversity. The area has a naturally high variety of species (in comparison to similar habitat/biotope features elsewhere) or includes a wide variety of habitats/biotopes (in comparison to similar habitat/biotope complexes elsewhere).
- Representativity. The area contains a number of habitat/biotope types, habitat/biotope complexes, species, ecological processes or other natural characteristics that are representative for the OSPAR maritime area as a whole or for its different biogeographic regions and sub-regions.
- Sensitivity. The area contains a high proportion of very sensitive or sensitive habitats/biotopes or species.
- Naturalness. The area has a high degree of naturalness, with species and habitats/biotope types still in a very natural state as a result of the lack of human-induced disturbance or degradation.

Under Annex V of the OSPAR Convention, contracting parties shall take the necessary measures to protect and conserve the ecosystems and the biological diversity of the maritime area, and to restore, where practicable, marine areas which have been adversely affected; and cooperate in adopting programmes and measures for those purposes for the control of the human activities. Aquaculture can be classified as a human activity, and will therefore need to be taken into account in the management of such areas. Judging from the criteria on which MPAs are selected, this is likely to impact areas that are of ecological significance and biodiversity. It must be noted that work is ongoing to identify habitats and species to be included within the OSPAR network of MPAs, with the network itself to be established by 2010.

3.2.5 Natura 2000 Sites

Natura 2000 is a European network of protected sites which represent areas of the highest value for natural habitats and species of plants and animals which are rare, endangered or vulnerable in the European Community. The term Natura 2000 comes from the 1992 EC Habitats Directive; it symbolises the conservation of precious natural resources for the year 2000 and beyond into the 21st century. The Natura 200 network will include SACs and SPAs.

Special Areas of Conservation (SACs): SACs are strictly protected sites designated under the EC Habitats Directive. Article 3 of the Habitats Directive requires the establishment of a European network of important high-quality conservation sites that will make a significant contribution to conserving the 189 habitat types and 788 species identified in Annexes I and II of the Directive (as amended). The listed habitat types and species are those considered to be most in need of conservation at a European level (excluding birds) (http://www.jncc.gov.uk/page-23).

EU regularly reviews how the directive is being implemented and will report member states to the Commission and European Court for non-compliance. Activities undertaken in such sites (e.g. aquaculture development) are subject to much greater interrogation of impacts.

Marine Special Areas of Conservation can be both intertidal and sub-tidal areas, and also land adjacent to the shore where it is used by marine species (Boyes, Warren & Elliott, 2003). In relation to marine areas, regulation 3(3) of the states that any "competent authority having functions relevant to marine conservation shall exercise those functions so as to secure compliance with the requirements of the Habitats Directive".

SAC designation requires Member States to establish conservation measures which correspond to the ecological requirements of Annex I habitats and Annex II species present on the site (Article 6.1), and to take appropriate steps to avoid deterioration of the natural habitats and habitats of species, as well as significant disturbance of species, for which the site is designated (Article 6.2). This includes the appropriate assessment of the implications of any plans or projects that, alone or in combination, are likely to have a significant effect on the site in view of the site's conservation objectives (Article 6.3). If a negative assessment is concluded, a plan or project can only proceed if it is for imperative reasons of overriding public interest and no alternative solutions are possible, and the Member State must take compensatory measures to ensure the overall coherence of the Natura 2000 network (Article 6.4).

Should aquaculture take place near SACs, it is likely to have an impact on the species and habitats for which the SAC was designated in the first place. As mentioned before, these species and habitats are listed under the Directive as they are considered to be most in need of conservation at a European level. Dunes are an example of such a habitat and is amongst a range of habitats assessed for their sensitivity to aquaculture in Section 3.

Special Protection Areas (SPAs): SPAs are strictly protected sites classified in accordance with Article 4 of the EC Directive on the conservation of wild birds (79/409/EEC), also known as the Birds Directive, which came into force in April 1979. They are classified for rare and vulnerable birds, listed in Annex I to the Birds Directive, and for regularly occurring migratory species (http://www.jncc.gov.uk/page-162).

The Directive provides a framework for the conservation and management of, and human interactions with, wild birds in Europe. It sets broad objectives for a wide range of activities, although the precise legal mechanisms for their achievement are at the discretion of each Member State. In particular, Article 1 of the Directive states that:

1. This Directive relates to the conservation of all species of naturally occurring birds in the wild state in the European territory of the Member States to which the Treaty applies. It covers the protection, management and control of these species and lays down rules for their exploitation.

2. It shall apply to birds, their eggs, nests and habitats[7]."

With regards to aquaculture development, the conservation status of the bird species will need to be taken into account if intervention is undertaken to reduce predation by birds, as well as the need to conserve and protect their habitats.

[7] http://europa.eu.int/eur-lex/en/consleg/pdf/1979/en_1979L0409_do_001.pdf

3.2.6 World Heritage Sites

Adopted in Paris, France in November 1972 and came into force in December 1975, the Convention Concerning the Protection of the World Cultural and Natural Heritage, is a unique international instrument in that it seeks to protect both cultural and natural heritage. The Convention defines the kind of sites which can be considered for inscription of the World Heritage List (ancient monuments, museums, biodiversity and geological heritage all come within the scope of the Convention), and sets out the duties of States Parties in identifying potential sites and their role in protecting them. Although many World Heritage sites fall into either the 'cultural' or 'natural' categories, a particularly important aspect of the Convention is its ability to recognise landscapes that combine these values, and where the biological and physical aspects of landscape have evolved alongside human activity (http://www.jncc.gov.uk/page-1371).

In Article 1 of the Convention, monuments, groups of buildings and sites are included under "cultural heritage". Under Article 2, natural features, geological and physiographical formations, and natural sites are included under "natural heritage". Under Article 4, it is the individual State's duty of protection, conservation, presentation and transmission to future generations of the cultural and natural heritage referred to in Articles 1 and 2 and situated on its territory (http://whc.unesco.org/pg.cfm?cid=175).

Aquaculture activities are not likely to have an adverse impact on cultural heritage. However, natural sites which are defined as "precisely delineated natural areas of outstanding universal value from the point of view of science, conservation or natural beauty" (http://whc.unesco.org/pg.cfm?cid=175) under natural heritage, maybe affected. Sites that are designated for their conservation value are of particular importance as their heritage could be threatened with duration and long-term effects to be taken into consideration.

3.2.7 Specially Protected Areas of Mediterranean Importance (SPAMI)

Sites which "are of importance for conserving the components of biological diversity in the Mediterranean; contain ecosystems specific to the Mediterranean area or the habitats of endangered species; are of special interest at the scientific, aesthetic, cultural or educational levels" (Article 8(2) of Barcelona Convention cited from UN Atlas of the Oceans (http://www.oceansatlas.org)). SPAMIs (Specially Protected Areas of Mediterranean Importance) may be created both within areas of national jurisdiction and on the high seas. It is applicable to the seabed, its subsoil and to the terrestrial coastal areas designated by each party, including wetlands. The protection and management measures applying in the SPAMI are those prescribed by the States proposing the SPAMI but all parties are to comply with such measures. Under Article 3 of the Convention, SPAMIs are established in order to safeguard in particular:

"(a) sites of biological and ecological value; the genetic diversity, as well as satisfactory population levels, of species, and their breeding grounds and habitats; -- representative types of ecosystems, as well as ecological processes;

(b) sites of particular importance because of their scientific, aesthetic, historical, archaeological, cultural or educational interest" (http://eelink.net/~asilwildlife/protocol_med.html).

Under Article 7, the Parties must in conformity with the rules of the international law progressively take the measures required, which may include "*e) the prohibition of the destruction of plant life or animals and of the introduction of exotic species*".

As with many of the other designations, SPAMIs are concerned with protecting sites of biological and ecological value. Impacts from aquaculture must therefore be minimised to prevent any deterioration to such sites which may result in prohibition of aquaculture activities.

3.3 STATUTORY INSTRUMENTS FOR NATURE CONSERVATION

Many of the designations presented above are supported by associated national / international legislative instruments. The table below summarises the spectrum of statutory instruments available for the management of the areas of conservation interest and includes a description of the hierarchy of law in existence. This table focuses on international and European scale legislation only.

Table 11: Statutory Instruments for Nature Conservation

International Legislation	Relevant Designated Area	Provisions
Council of Europe Convention on the Conservation of European Wildlife and Natural Habitats (The Bern Convention)	Biogenetic reserves Also transposed to Council Directive 79/409/EEC & 92/43/EEC	Chapter II - Article 4 - appropriate and necessary legislative and administrative measures to ensure the conservation of the habitats of the wild flora and fauna species & the conservation of endangered natural habitats. Special attention to the protection of areas that are of importance for the migratory species and which are appropriately situated in relation to migration routes, as wintering, staging, feeding, breeding or moulting areas. The protection of the natural habitats referred to in this article when these are situated in frontier areas.
UNESCO Man and the Biosphere Programme 1971 (not a statutory legislation, rather a worldwide programme officially launched by UNESCO in 1970).	Biosphere reserves (BR)	Biosphere reserves are established to protect areas of terrestrial and coastal ecosystems promoting solutions to reconcile the conservation of biodiversity with its sustainable use.
The Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR) 1992	Marine Protected Areas (MPA)	The OSPAR commission agreed in 2003 that a network of MPAs, according to the criteria and guidelines it adopted should be developed by 2010 and has written recommendations for how to go about this. Contracting parties are currently in the process of identifying and submitting initial sets of sites to the Commission.
Convention on Wetlands of International Importance especially as Waterfowl Habitat (the Ramsar Convention) 1971	Ramsar sites	Contracting Parties must designate suitable wetlands within its territory for inclusion as Ramsar sites with clearly defined boundaries. Each Contracting Party must formulate and implement their planning regime so as to promote the conservation of Ramsar sites.
The Convention Concerning the Protection of the World Cultural and Natural Heritage	World Heritage Sites	The Convention defines the kind of sites which can be considered for inscription of the World Heritage List (ancient monuments, museums, biodiversity and geological heritage all come within the scope of the Convention)
European Legislation	**Relevant Designated Area**	**Provisions**
Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora "Habitats and Species Directive"	Special Areas of Conservation (SAC)	To contribute towards ensuring bio-diversity through the conservation of natural habitats and of wild fauna and flora in the European territory of the Member States to which the Treaty applies. Measures taken pursuant to this Directive shall be designed to maintain or restore, at favourable conservation status, natural habitats and species of wild fauna and flora of Community interest (Article 2).

International Legislation	**Relevant Designated Area**	**Provisions**
Council Directive 79/409/EEC on the conservation of wild birds "Wild Birds Directive"	Special Protection Areas (SPA)	Article 1 – Relates to the conservation of all species of naturally occurring birds in the wild state in the European territory of the Member States to which the Treaty applies. It covers the protection, management and control of these species and lays down rules for their exploitation. It applies to birds, their eggs, nests and habitats. Article 3 – Preserve, maintain or re-establish a sufficient diversity and area of habitats, through the creation of protected areas; upkeep and management in accordance with the ecological needs of habitats inside and outside the protected zones; re-establishment of destroyed biotopes & the creation of biotopes. Article 4 – Member States shall classify in particular the most suitable territories in number and size as special protection areas for the conservation of these species, taking into account their protection requirements in the geographical sea and land area where this Directive applies.
The 1995 Protocol Concerning Mediterranean Specially Protected Areas and Biological Diversity in the Mediterranean (Barcelona Convention)	Specially Protected Areas of Mediterranean Importance (SPAMI)	The procedures for the establishment and listing of SPAMIs are described in detail in Article 9. SPAMIs may be created both within areas of national jurisdiction and on the high seas. It is applicable to the seabed, its subsoil and to the terrestrial coastal areas designated by each party, including wetlands. The extension of the geographical coverage of the new protocol (in comparison with the 1982 Protocol) was necessary in order to protect also highly migratory species such as marine mammals.
The Convention on the Protection of the Marine Environment of the Baltic Sea Area, 1992 (Helsinki Convention) (referred to as HELCOM Baltic Sea Marine and Coastal Biotopes in Table 13)		In the light of political changes, and developments in international environmental and maritime law, a new convention was signed in 1992 by all the states bordering on the Baltic Sea, and the European Community. After ratification the Convention entered into force on 17 January 2000. The Convention covers the whole of the Baltic Sea area, including inland waters as well as the water of the sea itself and the sea-bed. Measures are also taken in the whole catchment area of the Baltic Sea to reduce land-based pollution. The governing body of the Convention is the Helsinki Commission - Baltic Marine Environment Protection Commission - also known as HELCOM. The Helsinki Commission, or HELCOM, works to protect the marine environment of the Baltic Sea from all sources of pollution through intergovernmental co-operation between Denmark, Estonia, the European Community, Finland, Germany, Latvia, Lithuania, Poland, Russia and Sweden.

Adapted from S Boyes *et al*, 2003

In addition to existing legislation, the table overleaf describes pending legislation that will have relevance to this project.

Table 12: Pending Legislation for Nature Conservation

Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy' (EU Water Framework Directive or WFD)	The purpose of the Directive is to establish a framework for the protection of inland surface waters (rivers and lakes), transitional waters (estuaries), coastal waters and groundwater. It will ensure all aquatic ecosystems and, with regard to their water needs, terrestrial ecosystems and wetlands meet 'good status' by 2015. The Directive entered into force in December 2000 and Member States are required to transpose it into national legislation by December 2003. The Directive has a series of implementation deadlines which stretch to December 2015 (the date by which environmental objectives must be met).
The European Marine Strategy. Proposing an ecosystem-based approach to ensure conservation and sustainable use of biodiversity	In 2002 the European Commission made a communication to the Council and the Parliament entitled: "Towards a strategy to protect and conserve the marine environment" [1] (Marine Strategy). This communication presents an ambitious new approach to protect and conserve marine ecosystems and promotes sustainable use of marine resources. Responding to the threats faced by our oceans and seas, this new approach seeks to develop an integrated policy for the marine environment. The EU has, in addition to its environmental policy, a wide range of policies and programmes, such as fisheries, agriculture and transport, relating to the marine environment, but until now they have operated independently. The marine strategy represents a significant step forward in the development of a single, coherent policy for the conservation and protection of this most fragile resource. The overall policy in the Marine Strategy is to promote the sustainable use of the seas and conservation of marine ecosystems, including sea beds, estuarine and coastal areas, paying special attention to sites holding a high biodiversity value. The Commission will make proposals for developing an ecosystem-based approach, including ecosystem targets, to ensure conservation and sustainable use of biodiversity. Those proposals will be based on the concepts of favourable status of conservation and favourable ecological status as required by the Habitats and Birds Directives and the Water Framework Directive.
The Environmental Liability Directive	The Environmental Liability Directive aims to make those causing damage to the environment (water, land and nature) legally and financially responsible for that damage. By implementing the 'polluter pays' principle in this way, the Directive should ensure that environmental damage is repaired at the expense of the polluter, rather than the taxpayer. This should create a strong incentive for operators to avoid environmental damage in the first place. The Directive was adopted in April of this year. Member States have until 30 April 2007 to bring into force the appropriate laws and regulations to implement the Directive.

3.4 HABITATS AND SPECIES OF CONSERVATION IMPORTANCE

The study refers to the impacts of aquaculture upon the coastal and marine environments of environmentally sensitive sites. Freshwater and terrestrial habitats and species are outside the remit of this project. In order to understand the sensitivity of the designations to aquaculture, the assessment has to focus upon the habitats and species for which they are designated.

This section identified the sensitive habitats and animal groups within the designations which are the features for which the sites are designated. The assessment of aquaculture impacts on habitats and fauna will therefore focus upon sensitive and vulnerable habitats and animal groups. Once the impacts of aquaculture are understood in relation to the habitats and animal groups, an assessment of impacts on conservation designations can be estimated.

3.4.1 Habitats

The habitats listed in the table overleaf have been adapted from Annex I of the EU Habitats Directive[8] which lists habitats requiring strict protection due to their conservation status. These habitats have also been cross referenced to the EUNIS[9] habitat classifications. The EUNIS classification is a comprehensive pan-European system to facilitate the harmonised description and collection of data across Europe through the use of criteria for habitat identification (http://eunis.eea.eu.int/about.jsp) and has therefore been referenced to ensure compatibility across the EU community. The habitats are described along with their ecosystem importance and geographic distribution.

An initial screening has been undertaken to identify any source-pathway-receptor relationships between generic aquaculture activities and the receiving habitats. Where the screening has identified a relationship, the habitat has been taken through to the sensitivity analysis stage. The impacts of aquaculture on these screened habitats are described in Section 6.

3.4.2 Species

For the species, Annex IV and Annex I of the EU Habitats[8] and Birds[10] Directives have been consulted respectively. These Appendices list species that require strict protection due to their conservation status. The main animal groups that would be impacted from aquaculture activities have been identified for sensitivity analysis (see the table overleaf and Sensitivity Analysis in Section 6). This will provide a generic overview for each group, rather than analysing individual species themselves which would prove too exhaustive.

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[8] Council Directive 92/43/EEC on the Conservation of natural habitats and of wild flora and fauna "Habitats and Species Directive"

[9] EUNIS European Nature Information System

[10] Council Directive 79/409/EEC on the Conservation of wild birds "Wild Birds Directive"

3.5 INITIAL SCREENING OF HABITATS AND SPECIES

The table below has cross referenced the EU Habitats Directive habitats with those defined in EUNIS. This will ensure that the correct European standard classification of habitats and species has been consulted when assessing the designations and geographic coverage.

Table 13: Coastal and Marine Protected Habitats and Species

Habitat types of Conservation Interest [8]	EUNIS Habitat Type [9]	International/European Designation that would cover this habitat type	Geographical Coverage of the habitat within EU [11]	Is there an impact pathway from aquaculture activities to the habitat?	Habitat to be taken through to the sensitivity assessment stage (see Section 6 of report)?
COASTAL AND HALOPHYTIC HABITATS					
Open sea and tidal areas	A7 Pelagic Water column o A7.1 Neuston o A7.2 Completely mixed water column with reduced salinity o A7.3 Completely mixed water column with full salinity o A7.4 Partially mixed water column with reduced salinity and medium or long residence time o A7.5 Unstratified water column with reduced salinity o A7.6 Vertically stratified water column with reduced salinity o A7.7 Fronts in reduced salinity water column o A7.8 Unstratified water column with full salinity o A7.9 Vertically stratified water column with full salinity o A7.A Fronts in full salinity water column	o HELCOM Baltic Sea Marine and Coastal Biotopes 1998	A combination of: BE, CR, DE, GE, ES, GR, SP, FR, IE, IT, CY, LA, LI, HU, MA, NL, AU, PL, PT, SL, SK, FI, SE, UK	Yes	No
Sea cliffs and shingle or stony beaches	B2 Coastal Shingle o B2.1 Shingle beach driftlines o B2.2 Unvegetated mobile shingle beaches above the driftline o B2.3 Upper shingle beaches with open vegetation o B2.4 Fixed shingle beaches with herbaceous	o Barcelona Convention 199812 o HELCOM Baltic Sea Marine and Coastal Biotopes 1998 o Ramsar Wetland Types	A combination of: BE, CR, DE, GE, ES, GR, SP, FR, IE, IT, CY, LA, LI, HU, MA, NL, AU, PL, PT, SL, SK, FI, SE, UK	Yes	Yes

[11] BE Belgium, CR Czech Republic, DE Denmark, GE Germany, ES Estonia, GR Greece, SP Spain, FR France, IE Ireland, IT Italy, CY Cyprus, LA Latvia, LI Lithuania, HU Hungary, MA Malta, NL Netherlands, AU Austria, PL Poland, PT Portugal, SL Slovenia, SK Slovakia, FI Finland, SE Sweden, UK United Kingdom

Habitat types of Conservation Interest [8]	EUNIS Habitat Type [9]	International/European Designation that would cover this habitat type	Geographical Coverage of the habitat within EU [11]	Is there an impact pathway from aquaculture activities to the habitat?	Habitat to be taken through to the sensitivity assessment stage (see Section 6 of report)?
	vegetation o B2.5 Shingle and gravel beaches with scrub o B2.6 Shingle and gravel beach woodland B3 rock cliffs, ledges and shores, including the supralittoral o B3.1 Supralittoral rock (lichen or splash zone) o Unvegetated rock cliffs, ledges, shores and islets o Rock cliffs, ledges and shores, with angiosperms o Soft sea-cliffs, often vegetated				
Atlantic and continental salt marshes and salt meadows	A2.5 Coastal salt marshes and saline reedbeds o A2.51 Saltmarsh driftlines o A2.52 Upper salt marshes o A2.53 Mid-upper salt marshes and saline and brackish reed, rush and sedge beds o A2.54 Low-mid salt marshes o A2.55 Pioneer salt marshes	o EU Habitats Directive Annex I o Ramsar Wetland Types	BE, GE, DE, SP, FI, FR, GR, IE, IT, NL, PT, SE, UK	Yes	Yes
Mediterranean and thermo-Atlantic salt marshes and salt meadows					Yes
Salt and gypsum continental steppes	A2.52 Upper salt marshes o A2.528 Mediterranean (Limoniastrum) scrubs	o Council of Europe Bern Convention Res. No. 4 1996 o EU Habitats Directive Annex I o	SP, FR, GR, IE, IT, PT, UK	No	No
COASTAL SAND DUNES AND CONTINENTAL DUNES					
Sea dunes of the Atlantic, North Sea and Baltic coasts	B1 Coastal Dunes and Sandy Shores o B1.3 Shifting coastal dunes o B1.4 Coastal stable dune grassland (grey dunes) o B1.5 Coastal dune heaths o B1.6 Coastal dune scrub o B1.7 Coastal dune woods o B1.8 Moist and wet dune slacks	o HELCOM Baltic Sea Marine and Coastal Biotopes 1998 o Ramsar Wetland Types	A combination of: BE, CR, DE, GE, ES, GR, SP, FR, IE, IT, CY, LA, LI, HU, MA, NL, AU, PL, PT, SL, SK, FI, SE, UK	Yes	Yes
Sea dunes of the Mediterranean coast					
Continental dunes, old and decalcified					

Habitat types of Conservation Interest [8]	EUNIS Habitat Type [9]	International/European Designation that would cover this habitat type	Geographical Coverage of the habitat within EU [11]	Is there an impact pathway from aquaculture activities to the habitat?	Habitat to be taken through to the sensitivity assessment stage (see Section 6 of report)?
OTHERS					
Mussel bed communities	A1 Littoral Rock and Other Hard Substrata o A1.11 Mytilus edulis and/or barnacle communities	o Council of Europe Bern Convention Res. No. 4 1996	GE, DE, FI, FR, IE, PT, SE, UK	Yes	Yes
Seagrass beds on sublittoral sediments	A2.6 Littoral sediments dominated by aquatic angiosperms o A2.611 Seagrass beds on littoral sediments	o Council of Europe Bern Convention Res. No. 4 1996 o EU Habitats Directive Annex I	BE, GE, DE, SP, FI, FR, GR, IE, IT, NL, PT, SE, UK	Yes	Yes
Sandflats, mudbanks and sandbanks	A2 Littoral sediment o A2.2 Littoral sand and muddy sand o A2.3 Littoral mud o A5 Sublittoral sediment o A5.2 Sublittoral sand o A5.3 Sublittoral mud	o Council of Europe Bern Convention Res. No. 4 1996	BE, GE, DE, SP, FI, FR, GR, IE, IT, NE, PT, SE, UK	Yes	Yes
Maerl beds	A5 Sublittoral mud o A5.51 Maerl beds o A5.511 Maerl beds	o Barcelona Convention 199812 o Council of Europe Bern Convention Res. No. 4 1996 o Ramsar Wetland Types	BE, GE, DE, SP, FI, FR, GR, IE, IT, NL, PT, SE, UK	Yes	Yes
Kelp and seaweed communities	o A1.41 Communities of littoral rock pools o A3.11 Kelp with cushion fauna and/or foliose red seaweeds o A3.12 Sediment-affected or disturbed kelp and seaweed communities o A3.13 Mediterranean communities of infra-littoral algae very exposed to wave action o A3.21 Kelp and red seaweeds (moderate energy infra-littoral rocks) o A3.22 Kelp and seaweed communities in tide-swept sheltered conditions o A3.31 Silted kelp on low energy infra-littoral rock with full salinity o A3.33 Mediterranean submerged fucoids, green or red seaweeds	o A combination of: o Council of Europe Bern Convention Res. No. 4 1996 o Ramsar Wetland Types	A combination of: BE, CR, DE, GE, ES, GR, SP, FR, IE, IT, CY, LA, LI, HU, MA, NL, AU, PL, PT, SL, SK, FI, SE, UK	Yes	Yes

Habitat types of Conservation Interest [8]	**EUNIS Habitat Type [9]**	**International/European Designation that would cover this habitat type**	**Geographical Coverage of the habitat within EU [11]**	**Is there an impact pathway from aquaculture activities to the habitat?**	**Habitat to be taken through to the sensitivity assessment stage (see Section 6 of report)?**
	on full salinity infra-littoral rock o A3.34 Submerged fucoids, green or red seaweeds (low salinity infralittoral rock)				
Polychaete worm reefs	o A5.6 Sublittoral biogenic reefs o A5.61 Sublittoral polychaete worm reefs on sediment		BE, GE, DE, SP, FI, FR, GR, IE, IT, NL, PT, SE, UK	Yes	Yes
Animal Group Types of Conservation Interest [10]	Some Examples of Species Within the Order:	Designation that would Cover Groups	Geographical Coverage of the Groups	Is there an Impact Pathway from Aquaculture Activities to the Group?	Will the Group be taken through to the Sensitivity Assessment Stage?
Birds	<u>Procellariiformes</u> o Little shearwater (*Puffinus assimilis*) <u>Charadriiformes</u> o Arctic tern (*Sterna paradisaea*)	A combination of: o Barcelona Convention Annex II o Bern Convention o Bonn Convention Appendix I o Bonn Convention Appendix II o Bonn Convention. AEWA. o CITES Appendix I o EC Birds Directive o EC Fauna, Flora, Habitats Directive o IUCN Red List 2004	A combination of: BE, CR, DE, GE, ES, GR, SP, FR, IE, IT, CY, LA, LI, HU, MA, NL, AU, PL, PT, SL, SK, FI, SE, UK	Yes	Yes
Fish	<u>Acipenseriformes</u> Adriatic sturgeon (*Acipenser naccarii*)				
Mammals	<u>Carnivora</u> o Mediterranean monk seal (*Monachus monachus*) o Ringed seal (*Phoca hispida saimensis*) <u>Cetacea</u> o All species e.g. bottle nosed dolphin (*Tursiops truncates*)				

3.5.1 Habitats

The table above shows that not all coastal and marine habitats under the EU Habitats Directive will be included for the sensitivity assessment. In particular, open seas and tidal areas as well as salt and gypsum continental steppes are not to be assessed. This is due to the 'open' nature of these habitats. Water columns and steppes provide a baseline environment for many of the other outlined habitats to co-exist. For instance mussel bed communities are an important food resource for many species and so, if impacted by aquaculture, will in turn affect those species dependent upon them.

The initial screening has also shown that habitats can be further categorised to fit specific conditions, for instance shifting coastal dunes or coastal stable dune grasslands amongst other types within the "dune" category.

Those habitats which are to be taken forward for sensitivity analysis, will therefore be referred to under a generic heading and analysed as a whole. In summary, the habitats to be analysed are:

1. Reefs: mussel bed communities
2. Reefs: polychaete worm reefs
3. Seagrass beds on sublittoral sediments
4. Sandflats, mudbanks and sandbanks
5. Maerl beds
6. Kelp and seaweed communities
7. Saltmarsh communities
8. Sand dune communities
9. Shingle communities

3.5.2 Species

Out of the species listed in the EU Habitats and Birds Directives, the following groups of coastal and marine animals have been identified to carry out sensitivity analysis:

1. Cetaceans
2. Pinnepeds
3. Otters
4. Fish
5. Birds

Section 6 provides a brief description of habitat and species, coupled with their ecosystem importance and sensitivity thresholds. This is a generic description that does not focus specifically on the ecosystem importance for aquaculture *per se*.

4 SPATIAL ASSESSMENT OF INTERACTIONS BETWEEN AQUACULTURE AND ENVIRONMENTALLY-SENSITIVE AREAS

4.1 PURPOSE AND METHODOLOGY

A spatial database suitable for display and interrogation by a Geographic Information System (GIS) was developed for the project. The database was designed to store the spatial information collected for the project and also to store standard data tables. By accessing the database by means of a GIS, team members would be able to visually inspect the spatial information but also to associate tabular data with the spatial features to further the understanding of the study area. The intention of the database was twofold. Firstly, it was designed to provide a European wide overview of the areas of aquaculture production, environmentally sensitive areas and political boundaries, thus allowing the project team to appreciate the distribution of features around the study area. In order to accomplish this, the GIS used should be able to assemble disparate datasets depicting various political, environmental and aquaculture information. Secondly, by using GIS it should be possible to model the spatial relationships between environmentally sensitive areas and areas of aquaculture. As a minimum, the GIS should be able to output hardcopy in the form of maps.

4.2 DATA

In order to create a database of information suitable for use in the study a number of key datasets were necessary:-

- European base mapping;
- Aquaculture production areas;
    - Environmentally sensitive areas;
    - Natura 2000 sites.
    - Other environmental areas.

4.2.1 European Base Mapping

The base mapping for Europe was obtained in a format as per Nomenclature of Territorial Units for Statistics (NUTS) specification. For the purposes of this study the NUTS 2 level of detail was used, this specifies that each region of Europe shall have a minimum area of 800,000 m² and a maximum area of 3,000,000 m². This base mapping will be sufficiently detailed to allow for mapping of areas to a sub regional level. However, it was important to recognise that due to the geographic size of the overall study area it would be inappropriate to use data of a more detailed nature.

4.2.2 Aquaculture Production Information

As mentioned previously, one of the key datasets necessary for the appreciation of the spatial interaction between aquaculture and environmentally sensitive areas was a definitive set of aquaculture production areas. However, it became apparent that while there is information regarding production levels and methods, there is no suitable information available regarding the actual location of aquaculture. The lack of this key component removes the opportunity to perform any reliable spatial analysis using the aquaculture data. As a compromise, aquaculture production information was grouped together into a format that mirrored the NUTS 2 classification of Europe. By grouping the information in this way it was possible to join the production values with their corresponding NUTS 2 region in the spatial database. The results of this join can then be used to assess the distribution of aquaculture and related activities around Europe.

4.2.3 Environmentally Sensitive Areas

For the purposes of this study the environmental designations were grouped into two sets. The Natura 2000 network, both SPA and SAC, form the first set of designations. This was obtained from DG Environment via Spatial Applications Division Leuven (SADL). Unfortunately, the Natura 2000 data were not available for public access during the spatial assessment phase of the project and therefore a number of steps needed to be taken before the information was in a format suitable for use. The Natura 2000 network forms a vast database of information covering the whole of the European mainland and offshore areas. In order to make the information more manageable to the project, SADL performed a spatial intersection between the coastal NUTS 2 regions and the Natura 2000 features. The results of the intersection were forwarded to the project group for inclusion in the database. The second set of environmental designations consisted of UNESCO BioSphere Reserves, Ramsar sites, Council of Europe Euro Diploma and Biogenetic Reserves, Barcelona and Helsinki Convention areas. These were taken from a number of sources but primarily from the EU Data Service. In each instance, including the Natura 2000 information, each dataset was transformed into a format that was compatible with the GIS and thereby compatible with all other spatial datasets.

4.3 SPATIAL ASSESSMENT

Following the construction of the database it was possible to start appreciating the distribution of aquaculture and environmentally sensitive areas around Europe and their spatial relationships. A number of maps where produced from the GIS at European wide and region scales.

4.3.1 European wide maps

European Wide Natura 2000 Regions (4 maps): showing the distribution of Natura 2000 sites around the coastal NUTS 2 regions. For each Natura 2000 area the unique identifier is displayed, thereby providing a means of cross referencing the spatial data with the appropriate support information. These can be found in **Appendix D**.

European Wide Shellfish Production, 2003 (3 maps): These maps show the distribution of shellfish aquaculture around Europe. For each region, a pie chart indicates the quantity of shellfish being produced (in million tonnes per year) and also the proportion of shell fish type being farmed. Due to the absence of significant shellfish farming in the Northern European regions there are only three maps in this section. These can be found in **Appendix E**.

European Wide Fish Production, 2003 (4 maps): As in the shellfish maps each aquaculture region displays the quantity of fish being produced and the proportion of fish types being farmed. These can be found in **Appendix F**.

4.3.2 Regional maps

Maps showing aquaculture production for the top five fish and top four shellfish producing NUTS 2 regions (4 maps for shellfish as there was not the boundary data for Malta)

Top 5 finfish-producing NUTS 2 regions:

1. Highlands and Islands of Scotland (UK)
2. South West Scotland (UK)
3. Sterea Ellada (Greece)
4. Denmark

These can be found in **Appendix E**.

Top 4 shellfish-producing NUTS 2 regions:

1. Galicia (Spain)
2. West-Vlaanderen (Netherlands)
3. Bretagne (France)
4. Normandy (France)

These can be found in **Appendix F**.

For each region two maps are produced showing Natura 2000 areas and other conservation areas. For both map types, each designated area is labelled with either a unique reference number (for Natura 2000) or a site name (for other conservation designations.) In addition to the environmental information a table is displayed in each map detailing aquaculture production figures and techniques for that region.

4.4 RECOMMENDATIONS

While it is possible to gain an appreciation of the spatial relationships between areas of aquaculture and environmental designations, it is not possible to do so in any great detail with the existing datasets. In order to perform a detailed spatial intersection between environmental and aquaculture data it is necessary to understand the precise location of aquaculture sites around Europe. Ideally, a central coordinate or bounding polygon representing the extents of each particular aquaculture site should be acquired. Until this information is available it will only be possible to investigate aquaculture sites to the level of NUTS 2.

5 DETERMINATION OF PRINCIPAL PRESSURES ON SENSITIVE COASTAL ENVIRONMENTS FROM AQUACULTURE

This study evaluates the impact of the different pressures from aquaculture systems on sensitive environments. As will be seen in Section 7, the nature and scale of these pressures and the risk to sensitive environments vary widely between different production systems. Before these are assessed in detail, it is important to examine the different environmental pressures originating from aquaculture. The following table provides a list of the main pressures originating from European aquaculture as agreed at the Brussels workshop. This table also provides a linkage between these pressures and the main aquaculture production systems used in Europe.

Table 14: Linkage between Key Pressures and Aquaculture Production Systems

Pressure Categories	Production Systems						
	Cage farms	Shellfish rafts & longlines	Shellfish inter-tidal	Shellfish bottom culture	Land-based tanks	Land-based ponds	Lagoon culture
1. Sedimentation	Moderate	Moderate	Low	Low	Negligible	Moderate	Low
2. Change in bio-geochemistry	High	Moderate	Negligible	Negligible	Low	Moderate	Low
3. Change in coastal processes	Negligible	Negligible	Negligible	Negligible	Negligible	Moderate	Moderate
4. Infrastructure impacts	Negligible	Negligible	Low	Low	High	High	Low
5. Visual land & seascape modification	Moderate	Moderate	Negligible	Negligible	Moderate	High	Negligible
6. Disturbance	Moderate	Moderate	Moderate	Low	Low	High	Moderate
7. Predator control	High	Low	Moderate	Low	Low	Moderate	Moderate
8. Chemical use	High	Negligible	Negligible	Negligible	Moderate	Moderate	Negligible
9. Pathogen transmission	Moderate	Negligible	Low	Low	Moderate	Moderate	Low
10. Inter-breeding with wild organisms	Moderate	Negligible	Negligible	Negligible	Low	Low	Negligible
11. Introduction of alien species	Moderate	Low	Moderate	Moderate	Low	Low	Moderate

Level of pressure exerted: **High** **Moderate** **Low** **Negligible** **? Uncertain**[12]

Each of the 'pressures' exerted by aquaculture, identified above, are briefly reviewed in terms of their nature and linkages with aquaculture. This analysis is divided into two components:

Characterisation of Pressure: identified the nature of the pressure involved in respect of coastal aquaculture and describes some of the main characteristics involved.

Determination of Evaluation Variables: examines the main four variable axes of magnitude, significance, duration and distribution as described below.

- **Magnitude :** Refers to the quantum of change that is likely to be experienced as a consequence of a pressure (e.g. dissolved oxygen will be reduced by 50%).
- **Significance:** Refers to the potential impacts (ecological, social, economic) on the recipient(s) arising from the pressure. A pressure of small magnitude could result in a very significant impact and vice-versa. (e.g. siltation of a small bottom area with rare spices has low magnitude but very high significance). The degree of reversibility of the impact is considered part of its significance.
- **Duration:** Refers to the temporal scale (i.e. duration, frequency) of the pressure. It does not take into account the duration of impact(s) arising from the pressure.
- **Distribution:** Refers to the spatial scale of the area under pressure (e.g. the bottom below a sea cage as opposed to an entire gulf or sea loch) – sea overleaf for more details.

These variables are summarised in Table 50 on page 260.

[12] Negligible = undetectable; Uncertain = not known or insufficient data to categorise linkage

One essential element that is common to the first two pressures (sedimentation and changes in bio-geochemistry) is that of **spatial scale**. Although the waste input from a single fish farm can be treated as a point source, some of it may contribute to ecological pressures at a distance from the source. Furthermore, it may be necessary to consider the aggregate effects of several farms on a water body or the total impact of regional mariculture on a large area of coastal sea. It is thus important to consider the spatial extent of the ecological pressure and its impact. Although these depend in part on farming method and local environmental conditions, a general scheme proposed by the UK 'Comprehensive Studies Task Team' (CSTT, 1994; Tett *et al.*, submitted) has proven useful in understanding and managing impacts. It is illustrated in Figure 2 below and distinguishes three zones around a polluting point source such as a cage farm or an effluent discharge:

- **Zone A**: dissolved substances and free buoyant particles remain in this zone for only a few hours, and most sinking particles (including food, faeces and dead fish) reach the seabed here
- **Zone B:** dissolved nutrients (and other dissolved substances produced by farms) spread through and remain in this zone for a few days, giving rise to long-term increases in mean concentration, and the residence time allows phytoplankton biomass to increase significantly if light is adequate.
- **Zone C**: the regional scale, with water residence times of weeks to months, often spatially heterogeneous (e.g. with mixed, frontal and stratified waters), and only impacted by the aggregate output of large sources of pollutants; also important because it provides the 'farfield' conditions against which zone B changes should be considered.

Figure 2: Spatial Zones for Aquaculture

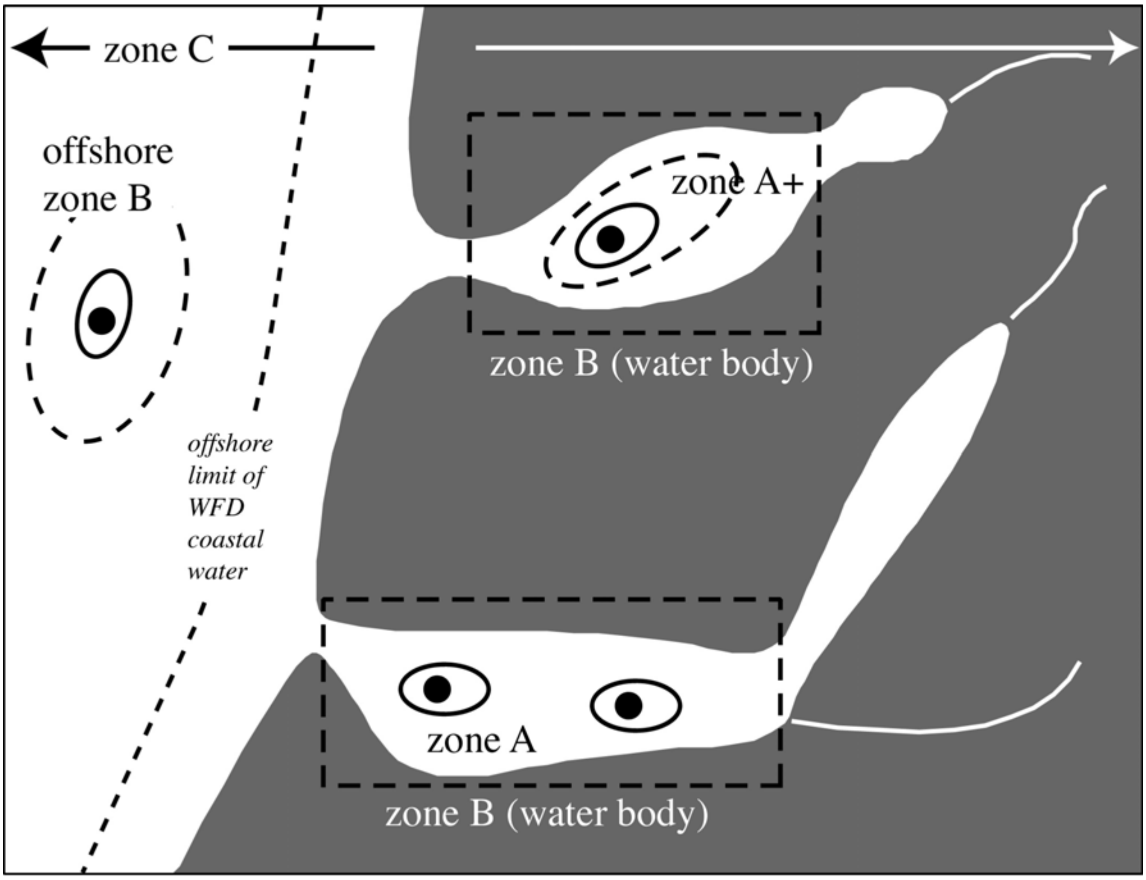


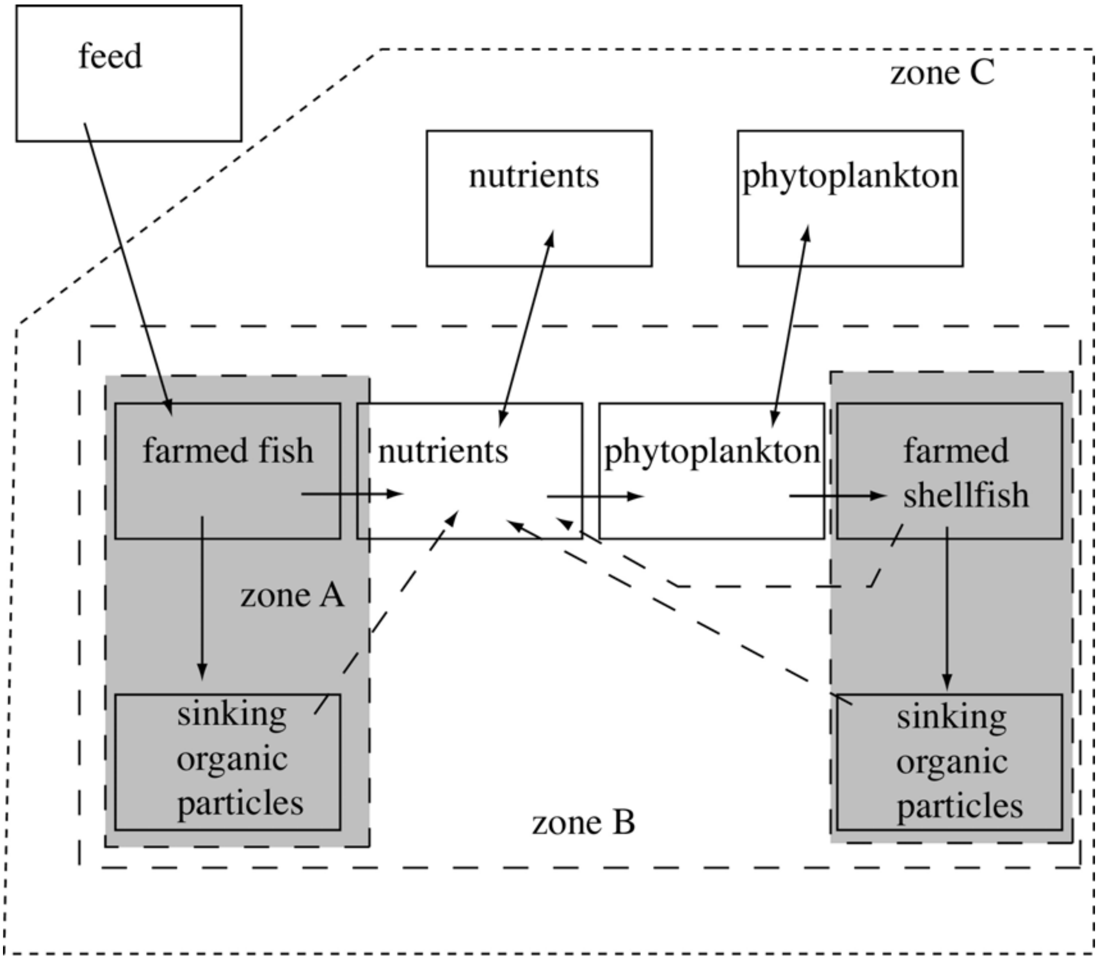
Table 15 compares the characteristics of each zone in respect of bio-geochemical pressures:

Table 15: Characteristics of Spatial Zones for 'bio-geochemical' pressures

Zone	**A: local to discharge**	**B: water body**	**C: regional**
Defining characteristic - residence time of unreactive neutrally buoyant tracer ; *and corresponding spatial scales*	A few hours *Metres*	A few days *Kilometres*	Weeks-months *Many kilometres*
Water column issues	Local maxima in concentrations of discharged toxic pollutants; local increase in turbidity because of particles released from farm; local decrease of dissolved oxygen because of consumption by fish; possible concentration of nekton around farm, but no significant (enhancement or depletion) effects on plankton	Long-term increase in mean concentration of pollutants, including nutrients; depending on flushing rate and light availability, extra nutrients may stimulate phytoplankton or seaweed production and biomass increase and transparency decrease; culture of filter-feeding shellfish may significantly deplete phytoplankton biomass	Regional contribution of farm nutrients to total budget; regional decrease in water transparency; potential increases in frequency of 'harmful algal blooms' (HABs) and regional production of organic matter; the regional scale also provides the 'boundary' conditions for zone b and these might be taken as 'reference conditions' if the zone c is not obviously perturbed
Seabed and nearbed water issues	Discharged particles sink to seabed (unless highly dispersive environment) where their decay may deplete sediment oxygen and form an anaerobic, organic rich layer of limited extent, generating H_2S and CH_4, smothering existing communities; (opportunistic) seaweed growth may be stimulated if shore or illuminated sublittoral within zone	Enhanced growth of annual seaweeds and epiphytic algae in shallow waters and on the sea shore; secondary effects of pelagic eutrophication including decreased light for seaweeds and seagrasses, and increased sedimentation leading to increased oxygen demand in waters beneath pycnocline; 'reference' conditions for discharges from single farms usually taken on this scale	Increase in duration or intensity of regional-scale hypoxia or anoxia where water is trapped below a seasonal or deep-water pycnocline; reduction in area of seabed suitable for growth of seagrasses or perennial seaweeds
Regulation	Deals with zone around single point source, controlled by farm (or discharge) consent conditions, short term 'ecological quality standards' (EQS) for water column and EQS and 'allowable zone of effect' (AZE) for seabed	Potentially deals with multiple point and diffuse sources; more difficult to regulate, needing long-term EQS and allocation of assimilative and carrying capacity	Requires aggregation of multiple inputs; and consideration of regional planning issues and the size of the maricultural industry
Concerns	Zone of obvious impact and public concern, and consequently has largely been well regulated during the last decade where mariculture established; still of concern in new regions of mariculture	Main zone of present concern in states with established mariculture because of planning issues and the WFD	Will become of increasing concern if industry grows in size

The Figure below summarizes some of the interactions between farms, nutrients, organic matter and phytoplankton according to scales. The scale issues have also been considered by Gyllenhammar & Håkanson (2005).

Figure 3: Interactions between Farms, Nutrients, Organic Matter and Phytoplankton According to Scales



Not included in the table or diagrams is a suggested 'zone D', which includes the distant regions from which a farm may take its food supplies, perhaps without concern for, or indeed knowing anything of, the sustainability or sensitivity of these distant ecosystems. An example is the harvesting of small clupeids to make feed for salmon in distant fjords. The wild fish caught to feed the 1,000 tonne farm of the previous subsection, represent the primary production of hundreds of square kilometres in an upwelling zone or in the North Sea, and a potential loss of food for larger fish. such as cod or tuna, and for fish-eating seabirds. Another type of 'zone D' is downstream from farming: it includes the load on urban waste water treatment plants from fish processing.

5.1 SEDIMENTATION

5.1.1 Characterisation of Pressure

Sedimentation from cage fish farms results from the deposition of particulate wastes including organic and inorganic constituents from faecal material (faeces and pseudofaeces arising from bivalve culture) and waste feed. Bivalve aquaculture, especially intensive raft mussel culture, redirects suspended organic matter to the seabed as faeces and pseudofaeces. Depending on the biomass of bivalve cultured and surrounding environment this can exert a significant environmental impact (Chamberlain *et al.*, 2001).

Identification of Pressures: Fish and shellfish production generates considerable amounts of solid waste (e.g. unconsumed feed, faeces and pseudo-faeces[13], shells and other detritus) that can have adverse impacts on the receiving benthic environment through organic enrichment of sediments or directly smothering of habitats and species. Organic matter in sediments is an important source of food for benthic fauna, however over-supply of organic matter, and the resultant anoxia or hypoxia as recorded at some fish farm sites, has been shown to give rise to changes in macrofaunal assemblages (Fernandes *et al.*, 2002, Karakassis *et al.*, 2000).

A variety of physical, chemical and biological changes occur in sediments exposed to continual deposition of organic waste from aquaculture. Where the rate of waste deposition, mainly in the form of faeces and waste food, exceeds the natural rate of breakdown in the sediments, a layer of this waste will settle on top of the natural sediment at the sea floor. This fine-grained, and often slimy, material has a very high organic content. In the absence of breakdown of this organic material, the sediments can become very acidic, and toxic gasses such as hydrogen sulphide and methane may be produced. In extreme cases, these gasses may bubble out through the sediments to the detriment of the fish in the overlying water mass. In these cases, there are generally no macrobenthic animals remaining in the sediments. If conditions are allowed to deteriorate, the sediments may become oxygen depleted or even fully anoxic. The deposited material on the sea floor may become blackish in colour, with a noxious smell and a layer of white, chemoautotrophic bacteria (e.g. *Beggiatoa* sp., *Achromatium* sp.) usually forms at the surface (Midlen and Redding, 1998). During the deterioration of healthy sediments, the community structure of benthic animals changes: the less resistant forms die out to be replaced by fewer, more tolerant forms, which then become more abundant. This predictable response forms the basis of the biological component of monitoring programmes. The depth to which the sediments are oxygenated gradually decreases, from often many centimetres deep, to a very shallow or even absent oxygenated layer. The depth of sedimentary oxygenation can be detected by measuring the redox (Eh) potential down the sediment profile (for example at 1 cm intervals). The point at which the sediment switches from being well oxygenated to anoxic is seen by a marked switch in redox potential readings, known as the redox potential discontinuity (RPD) layer. This is also a useful indicator of the status of the sediments and is widely used in many monitoring schemes (Black 2001). Specifically regarding the impacts of organic matter in benthic systems, there is a body of knowledge which derives from a variety of sources, including organic input from wood pulp waste, sewage sludge, as well as from observations beneath cages of farmed fish. Indeed, the conceptual model developed jointly by Pearson & Rosenberg (1976) on the basis of work in a Scottish loch and a Swedish fjord, provides the basis of current understanding of benthic disturbance due to organic enrichment.

[13] particles rejected during shellfish filtering and often bound in mucus

Sedimenting organic matter can be degraded during settlement in the water column (Diaz and Rosenberg, 1995) and, if sufficient oxygen is not supplied by mixing, then decreases in oxygen concentration may lead to hypoxia and in some cases anoxia in the deeper water. *Anoxia* refers to absence of oxygen, and *hypoxia* to conditions in which low levels of oxygen impose significant stresses on organisms. *Hypoxia* and *anoxia* are natural in some sea areas, and all seabed sediments are anoxic at some depth. Organic enrichment of seabed sediments occurs through the accumulation of POM, particularly in enclosed sea areas or where stratification causes stagnation, resulting in both a physical smothering of the sediment surface and an enhanced oxygen demand within the sediments. Whilst enhanced oxygen demand in both the water column and the sediments contribute to oxygen depletion within the benthic system, the highest oxygen demand is frequently in the water close to the seabed rather than in the sediments (Diaz and Rosenberg, 1995), and this is probably the result of POM in suspension here.

Assessments and understanding of solids deposition impacts reflect the historical development of finfish aquaculture, particularly Atlantic salmon, in Northern European waters. However later investigations have also studied impacts from the cultivation of other species, typically sea bream and sea bass, in southern European waters and especially the Mediterranean, and cultivation of shellfish (Karakassis *et al.*, 2001, Porter *et al.*, 1987).

The typical characteristics of the Mediterranean marine environment might result in considerable differences in impacts when compared with the patterns induced by the salmon industry in Northern European waters (Karakassis *et al.*, 2000). Primary physical differences are the microtidal regime, higher water temperature and greater light availability. Karakassis *et al*'s study, however, showed the significance of sediment type, coarse or fine, as being largely a factor of site exposure, for benthic effects as a result of deposition. This observation could also hold for Northern European waters.

<u>Environmental Impacts</u>: the impact on the seabed from solids deposition is the most obvious effect from fish farms, with severe effects largely being confined to the localised area (Scottish Executive, 2002). Impacts depend on the magnitude of deposition that occurs, which is itself a function of the scale of the site in question, the local hydrographic conditions and fish or shellfish biomass and husbandry practices at the site. The impact is generally quantified in terms of the degree of change to which the natural benthic community is altered and the spatial extent of this change. The following constitute the types of environmental impacts that may occur as a result of sedimentation at farm sites:

- Local blanketing of seabed by solids below cages or in the generally vicinity of shellfish rafts/racks causing smothering of sensitive species/habitats (e.g. Chamberlain *et al.,* 2001);
- Organic enrichment of seabed (localised and far field zones), altering conditions for sensitive species/habitats;
- Increased sediment oxygen demand (associated with organic enrichment);
- Impact on sediment C/N ratios (associated with organic enrichment);
- Far field deposition affecting sensitive species/habitats; and
- Deposition of associated nutrients, treatment chemicals, biocides.

Technological advances in cage design have allowed the development and farming on sites located in more exposed locations where, in general, impacts from solids deposition would be reduced. However, economic pressures to increase the scale of production may reduce this benefit.

Recoverability is determined by the sensitivity of the receiving habitats and species. Early in the development of moored cage aquaculture systems, located in sheltered sites, it was realised that the impact of allowing excessive (magnitude and duration) sediment deposition beneath the cages caused long term damage to benthic communities and even to the overlying water quality (Mutli *et al.,* 2001). Best practice is now considered to include destocking, or fallowing, a site after a growing cycle in order to allow seabed recovery prior to restocking (and also to minimise potential pathogenic impacts). Recoverability is addressed in more detail in Section 6.

Factors Contributing to Settlement
The settlement behaviour of these waste streams released into the water column will depend on a number of factors such as (Fernandes *et al.,* 2001):

- Type of aquaculture system – i.e. the level of production of solid waste in finfish or shellfish systems;
- Fish husbandry practices – i.e. feeding methods, growing cycle, stocking density;
- Hydrographic conditions – i.e. tidal & wind induced currents, wave action, water depth, temperature and salinity of the seawater and bottom topography;
- Composition, size and density of the particulate matter released which will affect settling velocity; and
- Geography of the area in question e.g. open, semi-open or enclosed water body.

The above factors can give rise to localised or far-field (regional) effects which are dependent on the methods used, site location, production scale, management approach and the assimilative capacity of the surrounding environment (Fernandes *et al.,* 2001). Solid waste produced from cage finfish farms has the potential to become dispersed at greater distances from the farm site, than that produced at a shellfish farm site. The environmental impacts in the cultivation of non-finfish species are localised and largely restricted to the immediate vicinity of the farm site, rather than far-field (Scottish Executive, 2002). Estimates of solid waste production from shellfish cultivation vary considerably. However, a significant proportion of solid waste is intercepted and consumed by animals on the farm and as a result, sedimentation reported in shellfish farms is usually considerably less than that for finfish farms (Chamberlain *et al.,* 2001).

The approach taken by farm operators in order to minimise the level of sedimentation at their sites now incorporates selecting sites with good water exchange and management practices that minimise food waste and chemical usage, which in turn allow for optimisation of fish health and growth (Fernandes *et al.,* 2001). Further, the use of 'high energy' (i.e. resulting in reduced ammonia-N loading) and 'low pollution' (i.e. high digestibility, low phosphorus) diets, along with the development of improved feeding management, have reduced the production of polluting wastes (IUCN, 2004).

The range of particle sizes and densities influence the settling velocities of solid waste particles emanating from finfish sites. These in turn are influenced by hydrographic conditions. For example, in shallow waters with weak currents, solid waste products will settle to the bottom close to the discharge point, which can give rise to a rapid accumulation of waste material on the seabed. In contrast, effluents released from sites into deeper waters, or where the bottom waters have strong currents, will be dispersed over a much larger area (Fernandes *et al.*, 2001). Hydrographic conditions are further influenced by seasonal variations and so consideration must be given to take into account different sea temperatures and seasonal upwelling/stratification of bottom waters.

Considerable effort has been invested in developing predictive methods to assess solids deposition and benthic impact beneath fin fish farms that can be used for site specific studies. Henderson *at al.* (2001) reported that, from the data available, relatively few models were used explicitly in regulation but many countries were using the tools, indirectly, to aid in the decision-making process. Model development had generally taken place in northern Europe, Canada and the USA where finfish farming had become a prime industry and the impacts of the industry widely contested.

In the UK, the model DEPOMOD (Cromey, 2002) was developed to provide a near field (<1 km^2) assessment for cage fish farms utilising input of local bathymetry, measured current speeds and known fish stocking densities and feed rates. The model was validated against field data from a number of sea loch sites in Scotland.

5.1.2 Determination of Evaluation Variables

Hyland *et al* (2005) have reported an investigation into the Total Organic Carbon (TOC) content of sediments as an indicator of stress in the marine benthos. The study collated a wide range of benthic study data from seven coastal regions worldwide, include Greek and UK coastal waters, to investigate benthic species richness in relation to sediment (TOC) concentrations. The study was not targeted at aquaculture impacts. Results gave sufficient consistency across all areas to allow the suggestion of TOC thresholds as general indicators of the likelihood of reduced sediment quality and associated bioeffects. At TOC concentrations below 10 mg/g it was suggested that the risk of benthic impact arising from organic loading and other associated stressors in sediments should be relatively low. At TOC concentrations greater than 35 mg/g the risk was high. At concentrations between these thresholds the risk of benthic impact was descried as intermediate.

The model DEPOMOD was adopted by the Scottish Environment Protection Agency (SEPA) as a regulatory tool and was adapted to provide predictions of in-feed medication concentrations on the seabed following ingestion, excretion and subsequent deposition (SEPA 2002, 2005). The model was renamed AUTODEPOMOD. Further development of this modelling approach has allowed assessments of the limiting stocking density, or biomass, at any individual site (SEPA 2004). This is achieved through use of the Infaunal Trophic Index (ITI) as an indicator of predicted benthic impact. ITI is a biotic index that describes changes in the feeding mode of benthic communities (Codling and Ashley 1992, Word 1978, 1980 & 1990) in response to pollution gradients. ITI scores range from 0 to 100 and are banded in terms of impact as;

- 60 < ITI <100 - benthic community normal
- 30 < ITI < 60 - benthic community changed
- ITI < 30 - benthic community degraded

ITI scores are calculated based on predicted solids accumulation on the seabed (g solids/m2.yr).

The AUTODEPOMOD model has been used by SEPA to define an allowable zone of effect (AZE), based on the predicted deposition environmental footprint, as bounded by the 30 ITI contour. This method would allow for a site specific AZE derived from local hydrographic conditions. For example, a site in a depositional location would have an AZE that was in extent, but enclosing a more severe impact, than a similar site in a dispersive location, which would have a larger AZE enclosing a less severe impact.

The approach used by DEPOMOD was adapted to Mediterranean environments through the MERAMED project (Black *et al.*, 2001) and the model is currently being adapted to the management of tuna farming and suspended shellfish farming (EU ECASA project of which some of the authors of this report are partners; http://www.ecasa.org.uk/Documents/ECASAnewsitem.pdf). No such method exists as yet to manage bottom culture.

Other methods now exist that can be used to assess the status of the marine benthos in relation to anthropogenic impacts, including aquaculture, namely the AMBI biotic index (Muxika *et al.*, 2005), the BQI (Rosenberg *et al.*, 2004) and the EQR (Borja *et al.*, 2004).

Magnitude: the magnitude of sedimentation impacts can be simply defined in terms of the maximum rate of deposition of solids on the seabed. This incorporates the solids loading from the site and the mechanisms affecting settling and distribution as a function of the local hydrographic conditions.

Significance: The significance of the impact reflects the degree of sediment enrichment and/or blanketing resulting from solids deposition and the effect that this has on the benthic community and any sensitive habitats present. At a low level organic enrichment can encourage species diversity and abundance but at higher levels diversity decreases as conditions favour opportunistic species. In highly enriched sediments very large numbers of a few pollution tolerant species can be observed. Ultimately, at excessive rates of solids deposition, sediment blanketing occurs with almost complete loss of benthic species.

Duration: The duration of the impact reflects the growing cycle of the species under cultivation, harvesting and the frequency of restocking at the site. Practices vary throughout Europe, and may reflect the stage of development of the industry in a particular region or for a given species. They may also reflect the degree of regulation imposed on the industry. Duration of impact also reflects the rate of recovery of the benthic community or habitat following cessation of solids deposition. The recovery of sites from intense organic pollution from fish cages or suspended shellfish culture, can take many years (Henderson at al 2001) and there is evidence that only an unstable equilibrium of benthic infauna and sediment chemistry is established in the sediments and that this can very easily be disrupted (Nickell *et al.* 1998; Karakassis *et al.* 1999).

Distribution: The distribution of deposited sediments beneath cages or rafts is a function of the local bathymetry and hydrographic regime. In this it is related to the impact magnitude. In low current speed environments, only limited distribution of the solids footprint occurs. As current speeds increase, greater dispersion of solids occurs during settling resulting in a more distributed footprint. Greater water depth at a site results in increased settling times and can also result in a more distributed footprint. In sites with relatively high near bed current speeds sediment erosion, resuspension and redistribution results in further distribution of the footprint. In high energy locations removal of a significant proportion of the solids from the footprint beneath the cages can occur, with the potential for resultant far field distribution at low levels.

5.2 CHANGE IN BIO-GEOCHEMISTRY

5.2.1 Characterisation of Pressure

Introduction

Like their wild cousins, farmed fish and shellfish need food. As a result of getting it, they grow, respire, and excrete. Such activities are not in themselves harmful, because the formation and consumption of organic matter, and the use and recycling of nutrient elements such as nitrogen and phosphorus, are natural functions of healthy ecosystems. Nevertheless, problems can arise when:

- the decay of too much organic matter removes oxygen;
- the presence of an excess of the nutrients gives rise to an accelerated growth of algae and higher forms of plant life to produce an undesirable disturbance to the balance of organisms present in the water and to the quality of the water concerned.

The second point refers to the process of eutrophication, as defined by OSPAR and in several EC directives, including that for Urban Waste Water Treatment (the 'UWWTD').

The maricultural pressures dealt with in this section arise from intensive or semi-intensive farming, which brings food produced extensively to be used in the small area of a farm. As an example, a farm stocked with 200,000 young salmon, and harvesting about a thousand tonnes of fish towards the end of a 2-year production cycle, uses about 1,200 tonnes of feed made from 3,600 to 5,900 tonnes of wild fish (Black, 2001). The food supply represents a share of the primary organic production of hundreds of square kilometres of sea. During the second year of the cycle the farm releases an amount of nitrogen, phosphorus, and faecal matter similar to that in the untreated sewage from several tens of thousands of humans. But whereas these people would inhabit at least a few square kilometres, even in the most densely settled European cities, typical cage farms of this size cover only a fraction of a square kilometre. Furthermore, whereas the UWWTD requires human and industrial wastes to be collected and treated before discharge, farm waste enters directly into the sea.

Thus, many fin-fish farms give rise to intense local inputs of organic mater and nutrients, and hence potentially create risks of oxygen deficit and eutrophication in the water column, decreases in water transparency that could slow the growth of seagrasses and seaweeds, and increases in the rate of sedimentation of particulate matter that could smother benthic communities. Shell-fish farms remove phytoplankton as well as inorganic particles from the water column, whilst increasing sedimentation fluxes and excreting nutrients.

The following table summarizes all categories of ecological pressure related to feeding and waste. These include the direct effects of sedimentation on the seabed, dealt with in section 5.1. This section 5.2. deals with the water-column (or *pelagic*) pressures associated with *biogeochemical changes* due to fish farming. Some of the water column pressures can lead to secondary benthic inputs and impacts, and these will be dealt with here.

Table 16: Pressures Generated by Each Type of Farming

The spatial extents of potential impacts are given in terms of the 'zones' around farms, considered in more detail in subsection 5.2.3. These scales or zones are: A (local to the farm), B (the water body in which the farm is sited) and C (the regional scale). n refers to no pressure from this source, at least, outside the farm itself in the case of land-based tanks and ponds. Lagoons are considered as self-contained water bodies which are managed as a whole in the interests of mariculture, so that no 'zone A' or AZE can be distinguished.

Pressure	Potential impact	Cage farms	Shell-fish farms (all types)	Land-based systems	Lagoon systems
Sedimentation of organic particles (waste food, faeces, etc) in regions of low or moderate dispersion	Increased organic input to seabed, increased oxygen demand, smothering of fauna, consequent anoxia and change in benthic community structure	A	A-B	n (A if in discharge)	B
Inorganic sedimentation (in mussel pseudofaeces)	Change in sediment composition	n	A-B	n	B
Oxygen depletion by fish- or shellfish-generated *BOD* ('biological oxygen demand')	Changes in behaviour wild animals, mortalities, benthic community change	A, B, C	A, B, C	n (A if in discharge)	B
Nutrient enrichment by excretion from fish or shellfish, or mineralization of their wastes	(potential risk of eutrophication, including changes in the balance of organisms and increased: biomass of phytoplankton, seaweeds and benthic and epiphytic microphytes; primary production; risk of harmful blooms; sedimentation; sea-bed shading	B, C	shellfish farms can enrich nutrients (B), but this does not lead to eutrophication because shellfish eat phytoplankton, although there may be subtle effects	n (B,C if in discharge)	B
Decreased abundance of phytoplankton (due to shell-fish demands)	Decrease in food supply for filter feeding animals	n	B, C	n	B

The physical and chemical environment

It is important to understand the physical environmental conditions that help to determine whether the ecological effects of mariculture are significant. These conditions include water movements and marine illumination. In addition this part of the text provides some background information about the quantitative chemistry of the elements featuring in biogeochemical change due to mariculture.

Waste discharged from a farm can be transported away from the farm by water currents or water turbulence. The former can be driven by wind, tide, river discharge, atmospheric pressure gradients, or larger scale circulation. The latter is the chaotic eddy motion of water that occurs when current speed varies across an axis at right-angles to the main flow. Eddies can occur on scales from metres to hundreds of kilometres, and eddy turbulence is a matter of scale: what is chaotic on one scale may appear as a system of currents on a smaller scale. In practical terms, a record made by a current meter at a fish farm site can be analysed into currents, which vary at a low frequency (which may be that of the tide) and turbulence, the high-frequency variation. It is often necessary to distinguish currents from turbulence, because the former moves packets of water in sequence, as if they were linked like the carriages of a railway train, whereas the latter mixes packets of water together. In some cases, however, it is simpler to refer to 'exchange' between one body of water and another, where an exchange rate gives the probability of a water or waste molecule being moved from one body to another in a given time. A water body of high exchange is thus one that can accept a large load of waste so long as it is exchanging with an unpolluted adjacent water. It is a particularly useful way of summarizing the main physical imports to and exports from a discrete water body of zone B scale. 'Dispersion' is a vaguer term, referring to the total effect of currents and turbulence in moving waste away from a farm site: it is, thus, treated here as a zone A process.

This account becomes complicated when the waste is denser than water and so sinks as it is being dispersed or exchanged. Most farm particulate waste sinks quickly, and so fails to be dispersed from zone A unless current speeds or local eddy turbulence is high. Under such conditions, even material that reaches the seabed can be resuspended and carried away. If 'the answer to pollution is dispersion and dilution' is indeed true, then high dispersion sites are the best places to put fish farms because dissolved as well as particulate wastes are spread out and their potential impact minimized. However, while the impact on zone A may be minimised, the aggregate impact on zones B or C may be increased by the aggregation of many discharges.

A further complication results from water layering. Such layering may be caused by solar heating of the sea surface, giving rise to a 'thermocline' separating a warm, wind-mixed upper layer from colder, deeper water. It can also be caused by freshwater input, because freshwater, like warm water, is lighter than salty or cold water. A ‘pycnocline’ is any layer (including a thermocline) in which water density increases rapidly with depth, separating superficial from deeper waters. Pycnoclines inhibit mixing between deep and surface waters, and can aid the development of hypoxia in seasonal deep water (beneath a summer thermocline, for example) or basin deep water (in a fjord) by preventing gas exchange with the air.

Photosynthetic organisms need illumination for their growth. Seawater is only moderately transparent, and sunlight falls below the illumination needed for the growth of phytoplankton or seagrasses at depths between 50 and 100 metres in even the cleanest and clearest parts of the Mediterranean. But seawater often also contains suspended particles, or 'yellow-substance' derived from land run-off, both of which increase the attenuation of submarine light. Thus the maximum depth for active photosynthesis can decrease to only a few metres in turbid coastal waters. Phytoplankton itself contributes to light absorption, and hence one of the consequences of eutrophication is a decrease in water transparency due to increased amounts of phytoplankton - in particular, amounts of the light absorbing pigments of phytoplankters, which are (green) chlorophyll and (yellow, brown or red) carotenoids, together with the bluish or reddish phycobilin pigments of cyanobacteria.

The organic matter that is increased directly by fish farm discharges, and indirectly by stimulation of additional photosynthesis by nutrient enrichment, is made from atoms of carbon (C), hydrogen (H), nitrogen (N), oxygen (O), phosphorus (P) and some other elements. Despite its oxygen content, organic matter is a source of energy that can be released by oxidation of the 'reduced' C and N. Complete oxidation typically requires 138 molecules of O_2 to convert 106 atoms of C and 16 atoms of N to carbon dioxide (CO_2) and nitrate ions (NO_3^-). A 'mole' (abbreviated 'mol') is the mass of a pure compound divided by the atomic mass of its constituent elements. For example, 62 g of nitrate ions, containing 14 g of nitrogen, are 1 mole of nitrate. Because organic matter is a mixture of types of molecules, it is better to refer to its constituent elements in terms of 'gram-atoms' (g-at).

Thus, decay of organic matter containing

- 1 gram-atom of carbon consumes (138/106 =) 1.3 moles of dissolved oxygen (O_2), taking account of the oxidation of the organic nitrogen;
- 1 g-at organic N gives rise to 1 mol 'DAIN'
- 1 g-at organically-combined P gives rise to 1 mol 'DAIP'

The acronyms 'DAIN' and 'DAIP' were proposed by the UK CSTT (1994) to distinguish between available and unavailable inorganic compounds of the nutrient elements. Thus 'DAIN' refers to 'dissolved available inorganic nitrogen', including ammonium, nitrite and nitrate ions, but excluding dissolved N_2 gas (which can only be used by some cyanobacteria). 'DAIP' refers to 'dissolved available inorganic phosphorus', mainly dissolved phosphate, but excluding particle-bound phosphate ions unless these are in equilibrium with free phosphate and hence potentially available.

The conversion ratios given above are used throughout this section. They assume that all fish farming organic waste is 'labile' - i.e. that it decays comparatively rapidly, at least on zone C timescales. They also assume that there are no losses associated with this decay; in some cases, part of the organic nitrogen might be lost to N_2 by the process of 'denitrification', which occurs when bacteria in organically-enriched sediments use nitrate rather than oxygen to oxidise the organic matter. Finally, the DAIN and DAIP terminology assumes that organic compounds cannot serve as sources of N and P for plants, algae and photosynthetic bacteria. This is not completely true: some micro-algae, at least, can use the organic molecule urea as a source of N. So 'DAIN' might be better understood as sometimes including a little bit of urea and similar, with minor consequences to the ratio of O to C, N and P. For present purposes, however, such complications are trivial.

Finally, the requirement for oxygen to mineralize labile organic waste will be referred to here as a 'Biological Oxygen Demand' or 'BOD'. Although this use is convenient, it is of course is a loose use of the technical meaning of the term 'BOD', which is the oxygen consumed when waste is incubated for a specific number of days (usually 5) at a specified temperature (usually 20°C).

The cultivated animals: their food needs and waste inputs

As already mentioned, food must be brought to the animals in intensive or semi-intensive mariculture, perhaps by transport of fish feed, perhaps by tidal exchange of water containing phytoplankton. It is this concentration of food that generates most of the ecological pressures discussed in this section.

The main inputs from finfish farming are compounds of nitrogen and phosphorus, in particular ammonium and phosphate and BOD (as defined above). The latter includes the respiratory demands of the fish themselves, and the potential oxygen consumption of waste organic matter, including fish faeces, when it is used as a food source by water column and sea-bed animals and micro-organisms. In all this, mariculture is no different from the farming of terrestrial livestock and poultry, or even from the life of humans in towns and cities. There are two important differences. First, aquaculture wastes often enter the aquatic environment directly, either because animals are farmed in natural bodies of water (e.g., salmon in cages) or aquaculture effluents are emptied into them (e.g., some shrimp ponds). Second, most farmed fish are carnivores and need a diet rich in protein and phosphates. However, even with the best management practices, the fish are inefficient users of this dietary N and P, and much of it enters the water directly as ammonia and phosphate (and related compounds) excreted by the fish, and indirectly through decay of fish faeces and uneaten food. The immediate nutrient products of decay are phosphate and ammonia, the latter being rapidly oxidized by way of nitrite to nitrate.

Thus we refer to the nutrient wastes as *Dissolved Available Inorganic Nitrogen,* or *DAIN,* and *Dissolved Available Inorganic Phosphorus,* or *DAIP*, as detailed above.

During recent decades, mass balance models have been developed to quantify the waste production of several species of farmed fish. Some of these are summarized in the table that follows, which shows that in most cases less than a third of the carbon, nitrogen and phosphorus supplied in food, is recovered in harvested fish. A mass budget model for silicon has been made by Holby & Hall (1994); although not included in the table, it may be useful in considering impacts of fish farms on the 'balance of organisms', as discussed below.

Table 17: Elemental budgets for fin-fish farming

(a) Salmonids

Constructed from data in Black (2001) and using the ratios for BOD and organic to inorganic nutrient conversion given in the earlier subsection. 1 kmol = 1000 moles. Note that fish feed is dry, whereas the harvested fish contain much water.

	C, g (g-at)	**N, g (g-at)**	**P, g (g-at)**
Fish feed (1200 g)	660 (55)	96 (6.8)	18 (0.58)
Harvested fish (1000 g)	139 (11.6)	26 (1.9)	3.2 (0.103)
Soluble wastes	323 (27)	46 (3.3)	4.9 (0.158)
Particulate wastes	185 (15.4)	22 (1.6)	9.5 (0.31)
Mortalities and escapes	13 (1.1)	1.9 (0.14)	0.4 (0.012)
	BOD, kmol	**DAIN, kmol**	**DAIP, kmol**
Total waste (per tonne of production)	52	6.9	0.48

(b) A variety of farmed fish

Sources as given. The outputs are given as a percentage of the mass of the nutrient element supplied in food. The soluble wastes are mainly ammonia (ammonium) and phosphate. The remainder of the budget is mainly particulate waste.

Source	**Species**	**Harvested (%)**		**Soluble wastes (%)**	
		N	**P**	**N**	**P**
Hall *et al.*, 1992; Holby & Hall, 1991	Trout	28	18	51	34
Gowen & Bradbury, 1987	Salmon	25		52	
Folke & Koutsky, 1989	Salmonids	25	23	62	11
Ballestrazzi *et al.*, 1994	Sea bass			31-34	17-29
Dosdat *et al.*, 1996	Sea bass			43-47	
Krom *et al.*, 1985	Sea bream	36	29		
Porter *et al.*, 1987	Sea bream	30		60	
Krom *et al.*, 1995	Sea bream	25		60	
Dosdat *et al.*, 1996	Sea bream			43-55	
Wallin & Haakanson, 1991	Various spp	21-30	15-30	49-60	16-26

Pond aquaculture is typically less detrimental to water quality than cages since pond walls contain the water. However, eutrophic effects depend on the frequency and volume of discharges, as well as the characteristics of the receiving waters. If ponds are rarely discharged, nutrient pollution is reduced because microbial processes and deposition inside ponds remove nutrients and organic matter. In some closed systems, recirculated water is stripped of its added nutrients; such systems, however, are energy-intensive.

It has been argued that filter-feeding mussels act as natural nutrient-strippers, by removing phytoplankton from the water. If the phytoplankton have grown using N and P originating from cages or tank discharges, then the harvesting of shellfish might indeed remove some of the added nutrients. However, in most cases, the food of mussels and oysters is natural phytoplankton, effectively harvested from the larger area of sea surrounding the farm. Much of the N and P in these pelagic algae are excreted by the molluscs, and thus an extensive mussel or oyster bed might contribute a zone B enrichment of nutrients. However, there is little risk of these nutrients causing regional (zone C) scale eutrophication because they can at most replenish the phytoplankton drawn on by the shellfish. Mollusc beds also act to enrich sediments with both organic matter (from phytoplankton) and fine inorganic particles (filtered from the sea along with phytoplankters). Some estimates of nutrient and organic loading from mollusc farming are given in the following table. It suggests that a hundred annual tonnes of mussel production consumes about 10% of the phytoplanktonic primary production in a square kilometre.

Table 18: Carbon and nitrogen budget for mussel farming

Based on the model of Dowd (2005), which gives values per kilogram of harvested mussels, at 80 animals/kg. . Assuming the FAO convention, these will be total live weight, including the shell; flesh weight is somewhat less.

Budget element	C, g (g-at)	N, g (g-at)
Phytoplankton and detritus consumed	1500 (125)	211 (15)
Harvested mussels (1000 g)	150 (12.5)	21 (1.5)
Soluble wastes	150 (12.5)	21 (1.5)
Faeces and pseudofaeces	1200 (100)	169 (12)
Losses to predators	0	0
Total waste (per tonne of production)	**BOD, kmol**	**DAIN, kmol**
	135	13.5

A final point is that the food needs and waste outputs of fish farms vary seasonally and with farm production cycles. The metabolic rates of most fish and all shellfish increase with temperature, and thus food demands and waste production are likely to be greater during summer and early autumn than in winter and early spring. The waste production of filter-feeding shellfish is greatest when their supply of phytoplankton or detrital food is greatest. Salmon are farmed on a 2-year cycle, with the greatest fish biomasses, and hence waste production, reached during the second year. All such variability is superimposed on the natural seasonal patterns of marine ecosystems, and the resulting complex pattern of interactions including seasons of greater or lesser risk of harmful impact.

Dissolved oxygen changes

There are many causes of change in the dissolved oxygen content of seawater, including changes in water temperature (and salinity), gas exchange at the sea surface, internal mixing of water of different oxygen content, and the photosynthesis and respiration of marine organisms. Like all other animals, farmed fish and shellfish consume oxygen, but the local impact of a farm is likely to be higher than that of a natural community because of the greater stocking density and faster growth of the farmed animals. In addition, the wastes produced by these animals represent a biological oxygen demand, which directly depletes oxygen, and nutrients released by a farm can increase photosynthetic production and thus add secondarily to the BOD in a water body.

A decrease in dissolved oxygen has been generally found in the water column around fish farms (Bergheim *et al.*, 1982; Beveridge & Muir, 1982; Beveridge, 1985; Phillips & Beveridge, 1986). Dissolved oxygen values returned to normal 30 m away from salmonid farms (Gowen & Bradbury, 1987) but an oxygen sag may extend to 1 km where trash fish is used and culture conditions are poor (Wu *et al.*, 1994).

In the Mediterranean, information on the levels of dissolved oxygen in the vicinity of fish farms is given only by La Rosa *et al.* (2002) for the area of central-west Italy. According to this study, oxygen values were close to saturation at surface during the entire sampling period (March 1997 to February 1998). Lowest saturation conditions were observed at 10 m depth in a mussel and a fish-farm areas.

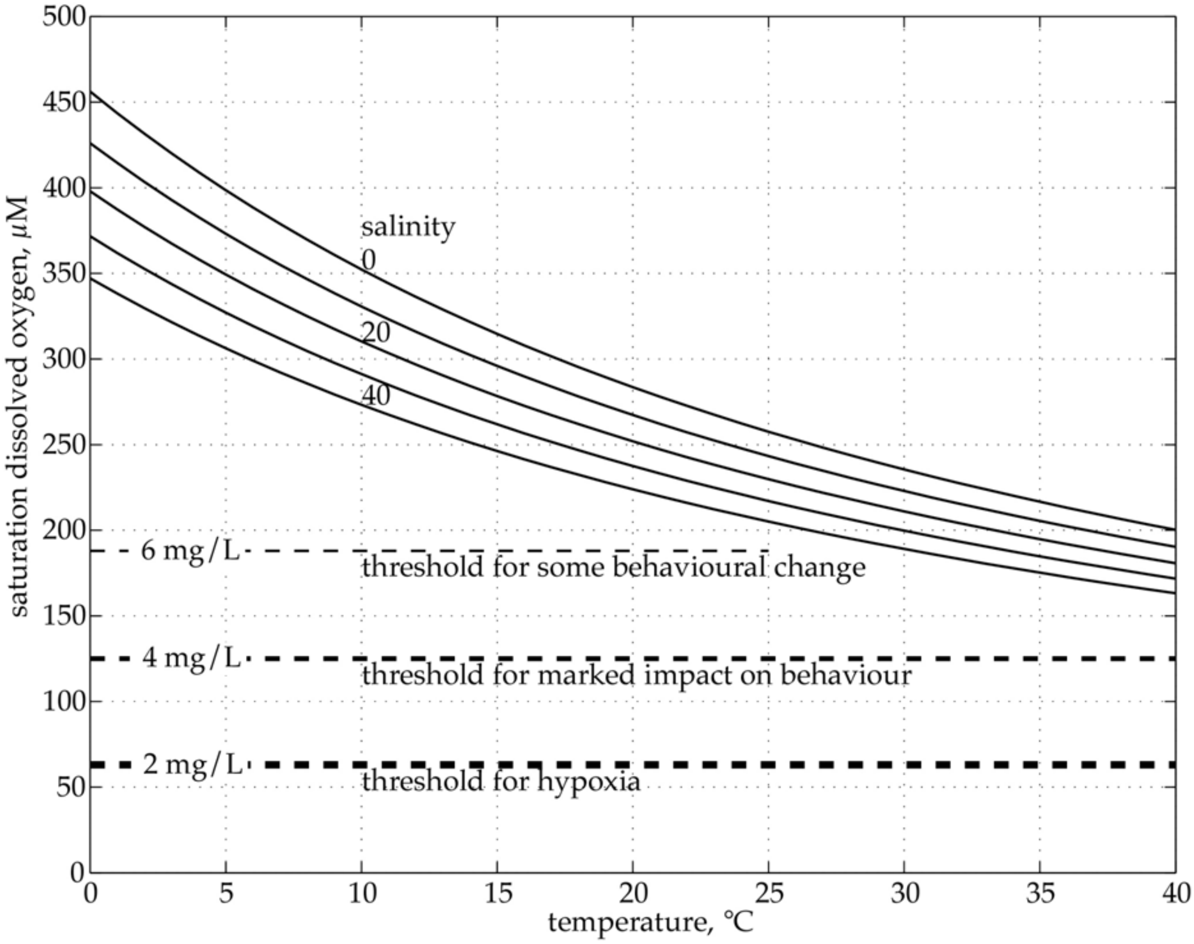
Whereas the local depletion of oxygen around a farm, compared with a more distant reference condition, is easy to relate to farm activity, it is often more difficult to relate larger scale (zone B and C) reductions to mariculture, because of both natural variation in dissolved oxygen and other anthropogenic inputs of BOD. The simple model considered in Section 5.2.2 aids such identification. As the model implies, the sensitivity of waters to any addition of BOD, whether natural or anthropogenic, varies depending on physical conditions. In particular, waters below seasonal thermoclines are typically and naturally depleted of dissolved oxygen during the summer, and dissolved oxygen may fall very low, or disappear completely, in waters below persistent pycnoclines in fjords. It is thus undesirable to input substantial anthropogenic BOD in such waters.

Dissolved oxygen is essential for the life of all multicellular organisms. A few specialist animals have adapted to temporary or small-scale anoxia by increasing their capacity to store or transport oxygen within their bodies or to slow their metabolism, but most aquatic animals depend directly on the availability of dissolved oxygen. The literature, summarized below, shows how increasing oxygen deprivation impacts on animal behaviour and life, and on community structure. Although the latter effects are best known for the benthos (Diaz & Rosenberg, 1995), studies in the Baltic Sea have shown how falling oxygen levels reduce the space available to fish populations (Neuenfeldt & Beyer, 2003). For an analysis of ecological communities sensitive to the different pressures originating from aquaculture, see Section 6.

Table 19: Critical Concentrations of Dissolved Oxygen in the Sea

Oxygen concentration	Benthic Effects	Source
0.5 mg/L	Catastrophic effect	(Gray *et al.*, 2002)
2.0 - 0.5 mg/L	Mortality	Gray *et al.*, 2002
4.0 - 2.0 mg/L	Metabolism affected	Gray *et al.*, 2002
6.0 - 4.5 mg/L	Growth affected	Gray *et al.*, 2002
4.0 - 2.0 mg/L	Change in trophodynamics & composition and abundance of benthic organisms	(Pearson & Rosenberg, 1978)
5.0 - 2.0 mg/L	Biological stress	(Bricker *et al.*, 1999)

Figure 4: Oxygen saturation as a function of temperature and salinity



The diagram shows how some of the thresholds in the table compare with the dissolved oxygen content of seawater when in free exchange with air at a range of temperatures. As can be seen, this *saturation* oxygen content decreases with increasing temperature: thus the availability of oxygen is less in the Mediterranean than in more northern European waters. Furthermore, the removal of a given mass of oxygen from each litre of seawater will cause a greater reduction in oxygen percentage content relative to saturation in warm waters compared with cold waters.

Nutrient enrichment and its consequences for phytoplankton and transparency

Aquatic *primary producers* include seagrasses, seaweeds, floating microalgae and cyanobacteria making up the phytoplankton and the seabed microalgae and cyanobacteria that make up the microphytobenthos. They are called *primary producers* because of their ability to make new organic matter by light-driven photosynthesis from water and carbon dioxide. Other necessary raw ingredients include compounds containing the nutrient elements, nitrogen (N), phosphorus (P) and iron (Fe), which are often scarce in near-surface seawater. Some micro-algae also need the element silicon (as dissolved silica) and certain vitamins. Eutrophication is defined (in EC directives and by OSPAR) as resulting from the *enrichment of water with compounds of nitrogen and phosphorus* since this can both stimulate primary producer growth or, by changing N:Si or P:Si ratios, influence the *balance of organisms*. The organisms that typically respond to this enrichment are those that can grow most rapidly: in particular phytoplankton and annual green or brown seaweeds.

Adding these nutrients to such waters may result in:

- increased growth of phytoplankton, with consequential:
    - increased water-column light absorption and hence sea-bed shading, making it more difficult for seagrasses or seaweeds to grow;
    - increased formation of organic matter, which may sink and decay, removing oxygen from seabed or deep water;
- changes in the 'balance of organisms' in the phytoplankton, resulting from change sin the balance of nutrient elements, including N:P and the ratio of either of these to silicon, used mainly by diatoms amongst microalgae; these changes can cause:
    - greater frequency of 'harmful algal blooms' because the new balance is less effectively controlled by grazing than the old;
    - increases in toxicity.
- increased growth of micro-algae growing on seagrasses or perennial seaweeds, harming them through shading or increased chance of disease;
- increased growth of opportunistic (rapidly-growing annual) green or brown seaweeds which can smother perennial seaweed beds or seagrass meadows.

'Harmful algal blooms' (HABs) are the subject of much debate. As Anderson & Garrison (1997) points out, they are only rarely 'harmful' and 'algal' and 'blooms'. Two broad categories may be distinguished:

- the occurrence, at low or moderate abundances, of species of pelagic micro-algae which contain toxins capable of strong effects on higher vertebrates, especially when these toxins are first concentrated by filter-feeding shellfish or fish: an example is the dinoflagellate *Alexandrium tamarense* with cells containing saxitoxins; when humans or other mammals or seabirds eat shellfish that have concentrated and stored the toxin as a result of feeding on the dinoflagellate, these consumers may suffer paralytic shellfish poisoning (PSP). (Hallegraef, 1993)
- the occurrence of genuine 'blooms' - i.e. large biomasses - of pelagic micro-algae, cyanobacteria or protozoans, which may be mildly toxic but have the greatest impact on humans through the formation of 'Red Tides' or beach foam, and on marine ecosystems through the sinking of the blooms or their organic products, resulting in the smothering of seabed communities.

The latter effects are paralleled by those of mass growth and decay of opportunistic green or brown seaweeds on nutrient-enriched shores of mixed soft and hard substrate.

The following table summarizes the pressures and potential impacts resulting from nutrient enrichment.

Table 20: Ecological pressures associated with nutrient enrichment

A (local), B (water body) and C (regional) refer to scales. n implies no inputs or effects on any scale. Lagoons are treated as self-contained water bodies.

Pressure	Potential impact	Cage farms	Shellfish farms	Land-based systems	Lagoon systems
Pelagic (phytoplanktonic) chlorophyll enhancement resulting from nutrient enrichment	Harmful blooms, increased sedimentation, increased shading	B, C	n	if nutrients discharged: B, C	B

Pressure	Potential impact	Cage farms	Shellfish farms	Land-based systems	Lagoon systems
Change in N:Si or N:P ratios	Change in balance of (pelagic) organisms, especially, ratios of diatoms: flagellates:cyano-bacteria; may increase risk from toxic phytoplankton	B, C	(B, C ?)	if nutrients discharged: B, C	B
Increased pelagic primary production resulting from chlorophyll and nutrient enhancement	More food for plankton, shellfish and fish, but also more risk of increased secondary sedimentation	B, C	n	if nutrients discharged: B, C	B
Decreased water transparency resulting from increased pelagic chlorophyll	Decrease in light available to seagrass and natural seaweed communities	B, C	n	if nutrients discharged: B, C	B
Smothering of natural phytobenthos by opportunistic seaweeds or epiphytic microphytes resulting from nutrient enrichment	Decrease in light available to seagrass and natural seaweeds, and in some cases killing by deoxygenation beneath opportunistic seaweed blanket	A, B	A, B	if nutrients discharged, B	B

As there are (so far) no plankton communities that have been identified as of conservation interest, and matters such as the impact of HABs on tourism or of food web changes on fisheries are outside the scope of the present work, the potential impacts needing consideration are those of:

- decreased transparency, increased secondary sedimentation, and increased growth of opportunistic seaweeds and epiphytes, on the benthic primary producing organisms that define their biomes or biotopes; these include: seagrass meadows; fucoid, kelp and other natural 'climax' seaweed beds; and maerl beds (which are formed by slow-growing red seaweeds);
- HABs on wild and farmed shellfisheries, other filter-feeding benthic invertebrates, and the birds and mammals whose well-developed nervous system makes them especially sensitive to algal toxins when these are concentrated by transmission within food webs;
- secondary sedimentation of BOD into regions beneath pycnoclines.

On the local (zone A) scale farm nutrients may directly stimulate growth of opportunistic seaweeds if the shore or shallow waters are nearby. In addition, free ammonia (i.e., dissolved NH_3) is toxic. It may reach locally high concentrations where large numbers of fish are confined in small volumes. Although the EC is in the process of reducing the EQS for free ammonium, it is only likely to have harm potential for local communities of organisms in cases of excessive stocking in poorly flushed waters. Such cases must be considered bad farm management as the ammonia may be harmful to the farmed fish themselves. Generally, only a small proportion of excreted nitrogen remains in the form of free ammonia, the rest rapidly ionizing to ammonium (NH_4^+).

On the zone B scale, one large fish farm can significantly enrich nutrient concentrations, but in many cases the regulators must take account of several or many point and diffuse inputs of nutrients. The potential for enrichment and for enhanced growth of phytoplankton or phytobenthos depends very much on the physical conditions in zone B, especially on:

- the rate at which the water in zone B is exchanged with or diluted by adjacent waters of lower nutrient and phytoplankton concentration;
- illumination conditions, and in particular whether the seabed is:
    - within the euphotic zone, when it might be expected to support growth of seagrasses, seaweeds or microphytobenthos
    - deeper than the euphotic zone, in which case the main users of added nutrients will be phytoplankters - but only so long as the euphotic zone includes a near-surface or midwater layer in which micro-algae or cyanobacteria can remain for sufficiently long to use the nutrients

The final bullet points implies that the potential for enhanced phytoplankton growth is greater in stratified water columns under conditions of good illumination: in high latitudes this tends to be the case only during Spring and Summer, but may be all-year-round in parts of the Mediterranean. Finally, the greatest potential for ecological disturbance occurs during seasons when nutrient levels are naturally low.

On the zone C scale, nutrient enrichment may be just one of several ecological pressures, adding its impact to those of climate change, removal of top predators and disturbance of the seabed by fisheries, and toxic pollution. All these pressures may sum to create an 'undesirable disturbance' (Tett *et al.*, submitted) to zone C scale ecosystems, and this would clearly be unfortunate for conservation features which depend on or are part of these ecosystems. Regulators and regional planners of the coastal zone must take account of the range of pressures; the regional scale impact of fish farming can be scaled by relating total nutrient inputs from farming to that from other point and diffuse sources including urban waste water, river and groundwater inputs, and atmospheric deposition. The specific effects are those already mentioned, and can be exemplified for the Baltic Sea, where nutrient enrichment (from urban and rural sources rather than fish farming) has been implicated in deep-water deoxygenation with consequential loss of benthic communities and damage to fish populations, increased blooms of cyanobacteria, and decreased water transparency leading to a shallowing of the lower depth limit of seagrass and perennial seaweed beds.

5.2.2 Impact of aquaculture on bio-geochemistry in the water column

Nutrient enrichment

In temperate waters, phytoplankton presents seasonal maxima in growth during spring and autumn as a result of nutrient availability due to mixing and other physical processes as well as adequate light conditions; surface nutrient depletion during the summer stratification period results in low phytoplankton growth despite the increased light availability. By contrast, the release of nutrients by fish farms is a continuous process throughout the year, reaching maximal values during summer when high water temperature imposes the need for higher feeding rates.

Furthermore, fish farming wastes provide dissolved nitrogen and phosphorus but not silica and therefore such wastes could be expected to favour the growth of certain phytoplankton groups such as flagellates or cyanobacteria (Parsons *et al.*, 1978; Doering *et al.*, 1989) at the expense of Si-limited diatoms. This modification of the structure of the phytoplankton community could in turn further affect zooplankton and subsequent trophic links since the quality of phytoplankton biomass as a food resource varies greatly among different phytoplankton groups (Bianchi *et al.*, 1993).

Beveridge (1996) reviewed a wide range of information sources including papers and technical reports and concluded that in marine waters, several studies have failed to establish a relationship between enhanced nutrient concentrations and phytoplankton growth. A response of the plankton community to hypernutrification became evident only in highly sheltered bays in the Eastern Baltic (Wallin & Hakanson, 1991) which is characterised by a microtidal regime and low-salinity. A review of the potential effects of fish farm nutrients on HABs in Scottish waters found little evidence of a link, but pointed out that this was as much due to 'absence of evidence' as 'evidence of absence' (Tett & Edwards, 2002). The results of the OAERRE project's study of 'regions of restricted exchange' were in fair agreement with the hypothesis that maximum observed chlorophyll concentrations correlated with nutrient loadings (Tett *et al.*, 2003), although at the sites studied most of the enrichment came from urban or agricultural sources.

The naturally oligotrophic character of the Mediterranean is widely acknowledged in terms of nutrient concentration (Béthoux *et al.*, 1992), transparency and chlorophyll *a* concentration (Williams, 1998). Given the existence of water column stratification and bright sunshine for much of the year, Mediterranean water columns might be expected to be especially sensitive to nutrient enrichment. The effect of aquacultural waste on the water column in this oligotrophic ecosystem has been addressed in a number of studies (Pitta *et al.*, 1999; Karakassis *et al.*, 2001; La Rosa *et al.*, 2002; Belias *et al.*, 2003; Karakassis *et al.*, 2005; Pitta *et al.*, 2005, 2006). The results from these may be compared with those from studies in other geographical areas (Nordvarg & Jahansson, 2002; Soto & Norambuena, 2004).

In the oligotrophic Eastern Mediterranean (Ionian and Aegean Sea), Pitta *et al.* (1999) reported a moderate increase in concentrations of phosphate and ammonium within the fish cages over the control site; however, this was not reflected in the chlorophyll *a* concentration or the abundance and community structure of diatoms, dinoflagellates and ciliates. Increased inorganic phosphorus and DOC concentrations and a minor response of heterotrophic picoplankton were found only in the waters overlying a fish farm in the Tyrrhenian Sea (La Rosa *et al.*, 2002). These studies have focused on the close vicinity of fish farms comparing them to respective reference stations. Belias *et al.* (2003) found increased ammonia, phosphate, silicate and DOC at cage stations in the Ionian Sea (Eastern Mediterranean) only occasionally. Nutrients became undetectable even at a distance of 8-30m from the cages (Pitta *et al.*, 2006). In addition, the phenomenon has a diel variability (Karakassis *et al.*, 2001; Pitta *et al.*, 2006). For instance, increased concentrations of phosphate were found around noon at the cages, i.e. during hours after maximum daily feeding, whereas a similar diel variability was not found at the reference stations. In contrast, no diel periodicity was detected for any of the biological variables examined (chlorophyll *a*, heterotrophic bacteria or cyanobacteria *Synechococcus*) at either the cages or the reference stations (Pitta *et al.*, 2006).

One possible explanation as to why a systematic effect on the water column variables is not usually detected, is the presence of strong currents in fish farming areas. Fish farms are located in areas with strong water currents in order to ensure adequate oxygen conditions and to protect farmed stock from infections and diseases. In this way, all wastes from fish farming, including inorganic nutrients excreted by fish and provided through fish feed, are transported away from the farms.

According to Gowen *et al.* (1983) the highly dynamic physical environment of fish farms is the main reason for which no trace of eutrophication (e.g. high chlorophyll *a* concentration) is found in their vicinity. Specifically, it is thought that due to rapid flushing time, phytoplankton are not present long enough to capitalize on high nutrient production. Soto & Norambuena (2004) suggested that increased nutrient concentrations are not usually found in the vicinity of fish farms not only because of dilution processes but also because they pass through the food web very rapidly, from phytoplankton upwards. This is also consistent with recent results by Machias *et al.* (2004, 2005) who found an increased abundance and biomass of wild fish in response to the presence of fish farming zones. The increase in biomass of wild fish by a factor of 2-2.8 reported by these authors implies that the mechanism of nutrient transfer up the food chain is particularly efficient.

Karakassis *et al.* (2005) have shown that there is little risk of hyper-nutrification on large spatial scales in the Mediterranean and concluded that water quality effects are likely to occur on short spatial scales. However, from many studies in the Mediterranean (Pitta *et al.*, 1999; La Rosa *et al.*, 2002; Belias *et al.*, 2003; Pitta *et al.*, 2006), it is concluded that at short spatial scales there is no systematic effect on water column variables by fish farming. Pitta *et al.* (2005) examined fish farming zones established in coastal areas where the presence of several farms producing several thousands of fish in the middle of an oligotrophic marine environment could be expected to cause visible effects at mesoscales. Only a few significant changes in some nutrient species were found at the deepest layer of the water column below the thermocline, and they were related to the remineralisation of benthic organic material.

The above studies from the oligotrophic Mediterranean Sea provide evidence that despite the large quantities of nutrients discharged by fish farms into the water column, there is little or low effect on biological variables related to water quality. There are indications that both dilution and grazing contribute to this process. However, the relative importance of each one of these is not known. Models can assist in investigating these points, as illustrated by Tett *et al.* (2003) for the Firth of Clyde in western Scotland. They concluded that the impact of anthropogenic nutrient enrichment was kept in check by grazing, especially that by protozoans, of phytoplankton.

Such conclusions about the Mediterranean may not hold true as total number or size of farms is increased. As discussed in the next subsection, models can help predict pressures and, perhaps, impacts of biogeochemical changes as nutrient and BOD loadings increase.

Dissolved oxygen

A decrease in dissolved oxygen has been generally found in the water column around fish farms (Bergheim *et al.*, 1982; Beveridge & Muir, 1982; Beveridge, 1985; Phillips & Beveridge, 1986). Dissolved oxygen values returned to normal 30 m away from salmonid farms (Gowen & Bradbury, 1987) but an oxygen sag may extend to 1 km where trash fish is used and culture conditions are poor (Wu *et al.*, 1994).

In the Mediterranean, information on the levels of dissolved oxygen in the vicinity of fish farms is given only by La Rosa *et al.* (2002) for the area of central-west Italy. According to this study, oxygen values were close to saturation at surface during the entire sampling period (March 1997 to February 1998). Lowest saturation conditions were observed at 10 m depth in a mussel and a fish-farm areas.

5.2.3 Modelling of bio-geochemical change

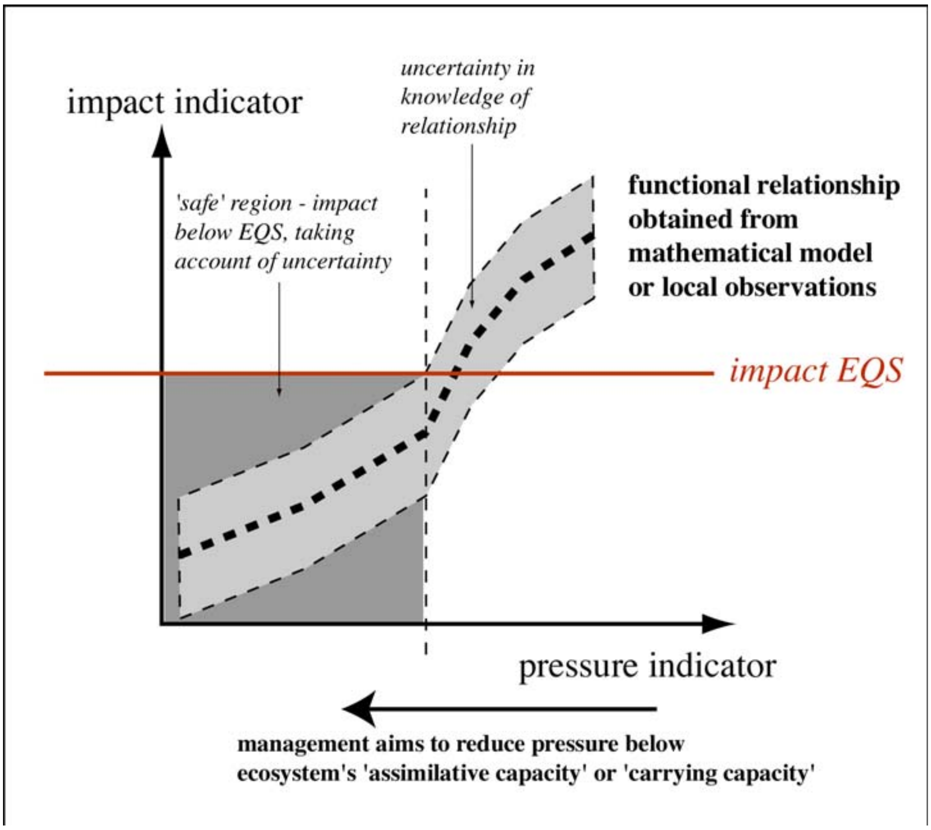
Mathematical models can be useful tools for predicting or managing biogeochemical changes because many of the changes can be described by Newtonian dynamical equations. In some cases, the equations can be solved for steady-state conditions. This type of tool is exemplified by the simple model shown in the box at the end of this subsection. It describes the effect of fish-farm generated biological oxygen demand on dissolved oxygen concentration.

In terms of the DPSIR approach, the oxygen model is a tool for estimating the **pressure** on a water body caused by a known farm loading of BOD. The estimated change in dissolved oxygen resulting from this loading can be compared with an Ecological Quality Objective (EcoQO), such as: *dissolved oxygen concentrations should not fall below 4 mg/L (125 mmol/m^3)*, and consented farm size can be regulated to ensure that the EcoQO is not breached.

Various models have been described that can be used to calculate ecological pressure from farm size and physical conditions. They include the 'Equilibrium Concentration Enhancement' (ECE) model for nutrient enrichment (Gillibrand & Turrell, 1997), the 'Comprehensive Studies Task Team' (CSTT) model for worst-case chlorophyll enhancement (Tett *et al.*, 2003) and the FjordEnv model for transparency decrease (Stigebrandt, 2001), all applicable to zone B 'regions of restricted exchange' as studied during the FP5/ELOISE project OAERRE [14].

Chlorophyll concentration can be seen as a pressure variable which can result in ecosystem state changes and therefore in **impacts** on organisms or communities that it is desirable to avoid. It can also be seen as the basis of an impact indicator, because increases in algal bloom frequency or amplitude might themselves be considered to show an undesirable change water quality. In the present context we are concerned with impacts on sensitive communities or populations. In principle, the strategy shown in Figure below can be used to ensure that such impacts do not breach EcoQOs, implemented in the diagram as Ecological Quality Standards (EQS).

Figure 5: Pressure-Impact Indicators and Models



In practice, the use of models to predict ecosystem **impacts** from pressures is complicated and difficult. One approach is by using ecosystem models, some of which are reviewed by Moll & Radach (2003). These contain one or more differential equations for each simulated ecosystem component, linked to physical models for water flows. Although the effort invested may be appropriate for dealing with zone C scales, it is unlikely to be available for routine management on zone B scales. The Norwegian MOM system exemplifies how monitoring and modelling can be combined to provide efficient management on zone A and B scales (Ervik *et al.*, 1997). The ongoing FP6 project ECASA [15] aims to develop a 'toolbox' of simpler models and empirical relations linking pressure and impact indicators. It is likely to prove more useful for managing farm impacts on the A and B scales.

[14] http://www.oaerre.napier.ac.uk
[15] http://www.ecasa.org.uk

Finally, the diagram also shows in a general way how **assimilative capacities** for farm waste, and **carrying capacities** for phytoplankton-consuming shellfish, can be estimated. In the case of wastes, models or empirical relationships can be used to explore the greatest discharges (from all sources) that will allow impact indicators to comply with EcoQOs. In the case of carrying capacity the variable to be managed is the removal of phytoplankton, or some part thereof, by shellfish. In the absence of sensitive communities or organisms, the EcoQOs are likely to be set by the need, under the Water Framework Directive, to keep all relevant biological quality elements at 'good' or 'high' status. The presence of protected organisms or communities may require more stringent EcoQOs.

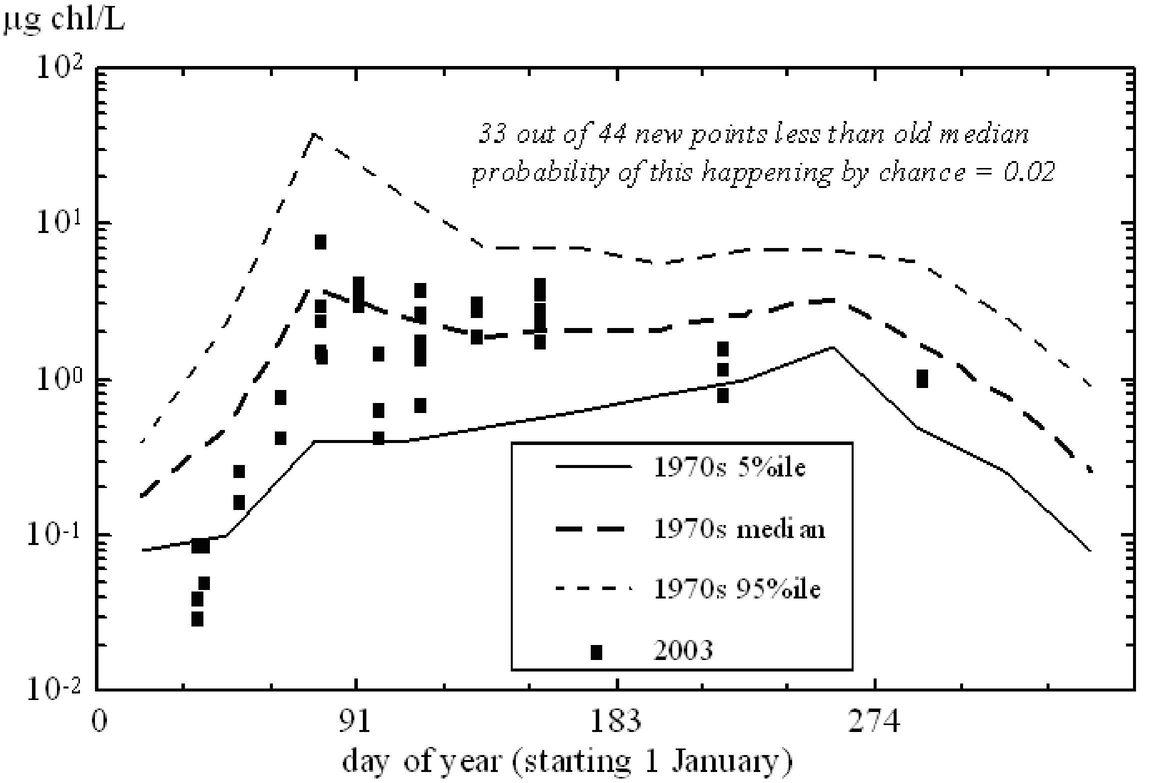
Determination of Evaluation Variables

<u>Magnitude</u>: the magnitude of biogeochemical changes is often expressed as a percentage of an appropriate reference condition, exemplified by a reduction in dissolved oxygen to 50% of the concentration at which seawater at that temperature is saturated. In the case of oxygen, smaller changes, down to 5%, can be easily detected using simple chemical titrations or electronic probes. In the case of nutrients, phytoplankton chlorophyll, and seawater transparency, change must be detected against a background of natural variability, a variability that is especially large for phytoplankton chlorophyll. In these cases, a change of 10% can only be detected by measuring many samples, and even then only when the reference condition is well known. Therefore, a change of 50% may be the least that can be easily and reliably detected.

The direction as well as the magnitude of change is also important: oxygen cannot exceed about 105% of saturation for long periods, because the excess is either lost through air-sea exchange, or by bubble formation. In contrast, nutrients, chlorophyll and transparency can either increase or decrease. An increase in first may cause an increase in the second, which is likely to cause a decrease in the third.

Where enough data are available, change may be better shown by an approach based on frequency. It is illustrated for phytoplankton chlorophyll in the following diagram, which shows an envelope for chlorophyll in a Scottish sea-loch (or small fjord) called Creran under reference conditions in the 1970s (Tett & Wallis, 1978). New data from 2003 (Laurent *et al.*, 2006) are overplotted; it can be seen that more than the expected 50% fall below the median line. In this case the result is the opposite of expectation, because the introduction of fish farming in Loch Creran was expected to enrich nutrients and result in increased chlorophyll concentration. The cause of the decrease has not been ascertained, although one hypothesis is that the removal of phytoplankton by shellfish farms in the loch more than offsets the effects of enrichment by finfish waste.

Figure 6: Demonstrating the magnitude of change in seasonally-varying chlorophyll in relation to a reference condition



Finally, quantification of changes in the 'balance of organisms' in the plankton, or of the frequency of harmful algal blooms, are possible, but suitable methods are still to be agreed amongst the scientific and regulatory communities, and will not be further considered here. See Tett *et al.*, (in review) for a further discussion.

Significance: the significance of oxygen depletion is, of course, that it can harm marine organisms, as already discussed. Painting *et al.* (2005) review two relevant Ecological Quality Objectives (EcoQOs) taken from the Bergen Declaration of 2002. They are:

- Oxygen concentration, decreased as an indirect effect of nutrient enrichment, should remain above region-specific oxygen deficiency levels, ranging from 4 to 6 mg oxygen per liter;
- There should be no kills in benthic animal species as a result of oxygen deficiency.

Tett *et al.* (in review) identified a breach of the first as relevant to the diagnosis of *undesirable disturbance* in the context of eutrophication, but considered that the second EcoQO was too severe. This was because local, short-duration, inputs of BOD naturally cause areas of benthic hypoxia with some animal death, and as such are part of the intermediate disturbance processes that maintain benthic biodiversity. The concept of an 'allowable zone of effect' (AZE) beneath cage farms, is rooted in this idea. Furthermore, the basin deep water of some fjords sometimes becomes anoxic due to natural accumulation of BOD during periods of stagnation. However, the duration, intensity and extension of oxygen deficiency has increased in some fjords, most likely as a result of anthropogenic nutrient enrichment of the supplying waters (Aure *et al.*, 1996). Since we are in this section not dealing with primary sedimentation, we need not further consider AZEs and zone A impacts. In addition to avoiding undesirable disturbance of communities, additional protection needs to be given to protected communities or organisms that are particularly sensitive to a reduction in water oxygen content.

We thus follow the Bergen declaration and Painting *et al.* (2005) in proposing a single EcoQO, which is that:

> *(Dissolved) oxygen concentration, decreased on zone B and C scales due to BOD addition or as an indirect effect of nutrient enrichment, should remain above region-specific oxygen deficiency levels, ranging from 4 to 6 mg oxygen per liter.*

As illustrated earlier, warmer waters hold less oxygen when saturated, and so the region-specific deficiency level should be set lower here; even so, a Mediterranean EcoQO is likely to be close to the saturation concentration during summer, indicating that organisms in such waters are likely to be harmed by relatively small changes in dissolved oxygen.

The significance of changes in other biogeochemical variables is less clear-cut. Painting *et al.* (2005) considered EcoQOs for nutrients and chlorophyll. They are:

- Winter DIN and/or DIP should remain below elevated levels, defined as concentrations >50% above salinity related and/or region-specific natural background concentrations.
- Maximum and mean chlorophyll a concentrations during the growing season should remain below elevated levels, defined as concentrations >50% above the spatial (offshore) and/or historical background concentration

Both are worth considering, although high nutrient concentrations give rise to enhanced phytoplankton only where illumination conditions allow, and neither nutrients nor chlorophyll are in themselves harmful. In contrast, changes in water transparency consequent on changes on chlorophyll can directly effect the health of subtidal seagrass and seaweed communities. Illumination which is less than 1% of that at the sea surface is likely to be too little for plant and algal growth, and the *compensation depth* at which this level occurs can be estimated from:

$$z_{comp} = 4.6/K_d \text{ metres}$$

K_d is the *diffuse attenuation coefficient* for downwelling sunlight. It can be estimated by measurements of submarine light at several depths, or, more simply and approximately, by measuring the depth at which a *Secchi disc* disappears from view. The effect of a 50% change in the coefficient is most marked when the attenuation is low - i.e. when water is transparent - under reference conditions. For example, increasing a clear water value from 0.05 to 0.075 m^{-1}, causes the compensation depth to decrease from 92 metres to 61 metres. In contrast, increasing a turbid water value of 0.3 m^{-1} to 0.45 m^{-1}, causes a decrease from 15 to 10 m and, most likely, a smaller decrease in the area of seabed receiving enough light for plant growth. In addition, the absolute increase of 0.025 m^{-1} in the clear-water attenuation can result from an increase in chlorophyll of only 1-2 mg chlorophyll m^{-3}, whereas the turbid-water increase of 0.15 m^{-1} will require an extra 10 mg chlorophyll m^{-3}, or more. (See Tett, 1990 for a more detailed discussion.)

These arguments suggest that a stringent transparency EcoQO should be applied when there is a risk of harming subtidal phytobenthos. We suggest the following:

> *Water transparency, measured as the reciprocal of the diffuse attenuation coefficient or the Secchi depth, should not decrease by more than 25% on zone B and C scales when there are sensitive phytobenthic communities present.*

Nutrient objectives are precautionary. We suggest one mainly because the equilibrium concentration enhancement of a nutrient by fish farming is simple to calculate, from:

$$\text{ECE (nutrient)} = \text{daily nutrient addition by farm/(water volume exchanged daily)} \quad \text{mmol m}^{-3}$$

This formula applies to all scales, but the proposed EcoQO is more restricted:

> *Equilibrium concentration enhancements of DAIN and DAIP due to mariculture should not exceed 50% of reference conditions in zone B.*

So far as zone C scales are concerned, maricultural inputs should be budgeted along with all other inputs of anthropogenic nutrient. Some European transitional and coastal waters, including waters used for shellfish farming, are already nutrient-enriched much above the 50% level, mostly by nutrients of agricultural, industrial and urban origin.

Dissolved ammonia (which should be distinguished from the ammonium ion) is not only a nutrient and a component of DAIN, it is also toxic in its own right. The normal standards should be applied to zone A, where concentrations might be enhanced by fish excretion. It is unlikely to give rise to zone B problems.

In the case of phytoplankton chlorophyll, we conclude that both increases and decreases should be of concern: the former because it can lead to decreased transparency as well as increased risk of algal blooms, enhanced sedimentation and deep-water deoxygenation; the latter because it reduces the food supply for filter-feeders. We thus suggest:

> *Changes in phytoplankton chlorophyll due to mariculture should not exceed 50% above or below reference conditions in zone B*

As already discussed, simple models can be used to estimate the amount and likelihood of such changes. Reference conditions are likely to carry seasonally and also on shorter timescales, giving rise to the well-known natural variability of phytoplankton abundance. For this reason it may be desirable to develop a frequency-based EcoQO and models that can predict probabilities of exceedance.

<u>Duration</u>: in most cases, pressures due to biogeochemical change vary on seasonal time-scales and those associated with growing cycles of the farmed animals; pressures are likely to be greatest at times when the water is warmest and the stock of fish or shellfish is largest.

<u>Distribution</u>: distributional issues have been interpreted in terms of the zones A, B and C for biogeochemical changes. In summary:

- **Zone A scale**: increases in ammonia, and decreases in dissolved oxygen, should be considered; however, the main impact of large changes is likely to be on farmed animals themselves;
- **Zone B**: increases in DAIN and DAIP concentration, changes in chlorophyll concentration, and decreases in dissolved oxygen and water transparency, should be considered ; in stratified waters, chlorophyll increases are likely to be found mainly in surface waters, whereas oxygen deficit is a greater risk in deeper waters;
- **Zone C**: on this scale, changes in nutrients, chlorophyll, oxygen and transparency can result from several anthropogenic drivers, and pressures arising from mariculture should be assessed in this context.

5.3 CHANGE IN COASTAL PROCESSES

5.3.1 Characterisation of Pressure

Aquaculture activities, in particular land-based ponds and lagoon culture, can impact upon coastal processes through compartmentalisation of the waterbody (within an estuary) or through clearance of coastal (nearshore) vegetation. Impacts such as excessive sedimentation which interfere with natural coastal sediment transport processes can occur. This in turn can lead to increased beach erosion and loss of benthic habitats.

Water supply may also be affected with hydrological processes, or water levels being affected. Developments can affect current velocity, and in particular sheltered areas or inlets where lagoon culture may take place, can be adversely affected.

There are few impacts on water column processes, though the following tables identify those types of aquaculture development that have an impact on coastal processes and vice versa.

Table 21: Aquaculture and Impacts on Coastal Processes

	Level	**Types**	**Typical species**	**Characteristics**	**Impacts on Coastal Processes**
Finfish	Intensive	Land-based tanks and raceways	Salmon, *sea bass* (FR) and sea bream (FR), turbot, sole & eels	Often very high intensity production with controlled flow rates and recirculation. Small environmental footprint, often covered and possible to control effluents.	Negligible
		Sea cages	Salmon, *sea bass*, sea breams, halibut, cod	Relies on good initial siting as dependent upon site environmental conditions. Permit less control than pump-ashore systems but sites are less costly and movable.	Minor alterations to nearshore currents
	Semi-intensive	Pond culture	Mullet, sea bass and sea bream, shrimp	Larger environmental foot-print than the above, either situated above the high tide in low-lying coastal plains (e.g. salt marshes in Portugal). Usually used for lower density culture of shrimp or finfish e.g. mullets, sea bass and sea bream. May require extensive effluent settlement areas.	Potential small impact on beach sediment drift.
	Extensive	Lagoon culture	Mullet, sea bass and sea bream, shrimp	Traditional methods (e.g. Italian *vallicoltura*) using natural fry and no or limited supplementary feeds. May require compartmentalisation of natural lagoon areas.	Impact on lagoonal hydrodynamics, not open sea hydrodynamics
		Ranching	Salmon, lobster, cod	Restocking of species which are either migratory, returning close to the point of release (e.g. salmon), or non-migratory, remaining for at least a substantial portion of the life-cycle in restricted areas, where they enter the local fishery (e.g. lobster).	Negligible

	Types	**Typical species**	**Characteristics**	**Coastal Process Impacts**
Shellfish	Suspended rope culture	Mussels, oysters (Mediterranean)	Ropes, covered with spat kept in place by nylon nets, are suspended either from rafts, wooden frames or from long lines of floating plastic buoys.	Negligible
	Bottom culture	Mussels, oysters, scallops	Seed mussels are relayed in suitable grow-out sites.	Negligible – possible localised sediment impacts
	Rack culture	Oysters	Oysters are laid out on wooden trestles or racks laid out in the intertidal zone.	Negligible
	'Bouchot" culture	Mussels (France)	Uses a series of wooden poles as supports, onto which the mussels are transplanted for on-growing	Negligible
	Ponds	Oysters, shrimp	In France, a special treatment (*'affinage'*) may be applied for the supply of top quality oysters - prior to selling these are placed in former salt marshes which have been converted into ponds (*'claires'*)	Negligible on open sea hydrodynamics
	Lagoons	Clams	Juveniles are released into controlled marine areas (lagoons, salt pans, large ponds or 'parks' in the open sea)	Possible localised alteration to tidal currents.

Land-based ponds and lagoon aquaculture often involve the compartmentalisation of wetland or lagoon waterbodies, with resultant impacts on their hydrology and sediment transport patterns. Other forms of aquaculture tend to have little impact on waterbody processes.

5.3.2 Determination of Evaluation Variables

The magnitude of coastal process impacts could be considered as the amount of change in either littoral drift rates, suspended sediment load, contemporary hydrodynamic regime (i.e. currents etc) that may influence the water quality of the site. Some indicators of magnitude threshold are highlighted below.

The significance could be considered as the degree of change in contemporary coastal process and coastal hydrodynamics (i.e. littoral drift rates etc) and the resulting implications this may have on the sediment budget of the area (i.e. net benefit or loss to the prevailing sedimentary/hydrodynamic regime).

The duration could be considered as the temporal impact of the potential change in sediment transport rates or coastal hydrodynamics over the lifespan of the development .

The distribution could be considered as the spatial scale of any alterations to sediment transport rates/current speeds over local and more regional spatial scales.

5.4 INFRASTRUCTURE IMPACTS

5.4.1 Characterisation of Pressure

Like other forms of food production, aquaculture requires infrastructure – such as ponds, dykes, canals, buildings and roads - which will result in a degree of habitat modification. In some cases this can take place in areas without significant ecological interest, even on brownfield sites (i.e. land-based tank systems). In others, it may be that the best sites in terms of their access to seawater, the cost of land and its development may be low lying areas adjacent to or even within the inter-tidal area. As a result, site development might result in the direct removal or displacement of habitats or species, or a decline in the structure and function of that ecosystem, both in isolation and as part of the overall ecological network. For instance the development of wetland or lagoon areas for aquaculture purposes might result in changes to hydrological and sediment transport patterns.

5.4.2 Determination of Evaluation Variables

The impacts of habitat modification vary considerably between the different aquacultural activities and the receiving habitat. However, the following thresholds have been identified following a review of Environmental Impact Assessment criteria. It should be noted that habitat modification can be direct or indirect and the following thresholds are of use, therefore, as an initial guide only as the magnitude and severity will be dependant upon the nature and type of receiving habitat and the type of habitat modification occurring. Types of habitat modification include:

- Direct removal (dredging: single or reoccurring activity)
- Direct removal (building)
- Changes to coastal processes or hydrology

The magnitude. The magnitude of the impact is the severity of the impact upon the receiving habitat or species and the likely loss of environmental integrity that might result. The actual effect will dependent upon the sensitivity of the habitat or species to that impact.

The significance could be considered as the degree of change in the habitat being modified, the sensitivity of the receiving habitat or the combination of a number of different forms of habitat modification. The significance will also be directly dependant upon the level of legal protection of the receiving habitats or species and as to whether the impact is deemed to have compromised the integrity of the site.

The duration could be considered as the period of which the impact lasts. Impacts may be confined to the construction period, the period of operation or many even extend beyond the cessation of activities and decommissioning of the farm.

The distribution could be considered as the spatial scale of effect of the habitat modification. This might vary from no detectable change to a detectable impact within the footprint of the site or externally to the site footprint and could impact the integrity of the features or site integrity to the impact extending beyond confines of the site and will significantly affect the features and site integrity.

5.5 VISUAL LAND AND SEASCAPE MODIFICATION

5.5.1 Characterisation of Pressure

It is of benefit to all that the landscape and seascape environment is managed sympathetically, and with broad social, economic, cultural and environmental needs in mind. As the aquaculture industry expands, it will become more difficult to identify new locations where landscape can accommodate the scale and nature of this type of development. In addition, the incremental expansion of individual fish and shellfish farms around Europe will be increasingly difficult to accommodate depending on the scale of the coastline in question. Nevertheless, well located developments can positively contribute to landscape character, and create opportunities to reinforce the landscape as a working environment.

Perceived wildness and sense of remoteness are valued as a diminishing resource, but in addition, the rich variety and distinctiveness of the character of all our landscapes is recognised as an important asset. All developments need to respect the diversity of landscape character and sustain the qualities which reinforce experience of place. With careful siting and layout, aquaculture can make a positive contribution to revitalising the landscape, for example through reusing redundant buildings and introducing an energising sense of human activity.

The nature of many different European coastlines means that aquaculture development is often highly visible, either from land or sea. The importance of visibility, whether in relation to classic vistas, or as a contribution to the experience of place, cannot be underestimated. Aquaculture should not need to be hidden from view, but should be well enough sited and designed to fit in with the surrounding character and contribute to a lived in landscape.

Physical character, human activity, visual qualities and experience of place often combine to create a landscape character which is distinct across a geographic area. Aquaculture developments can undermine characteristics which contribute most significantly to the landscape character of an area. The process by which these key characteristics are identified and assessed is called landscape character assessment.

In general terms, structures in and on the water are often very visible due to:

- the contrast in texture between the cages or lines and the smooth, reflective surface of the water, particularly in calm weather;
- the contrast between the vertical sides of cages and infrastructure and the water surface;
- the constant changes in light conditions which one moment can cast a structure into shadow, and the next reflect bright light upon it;

- the changes in sea colour and tone which can often camouflage the structures one moment, but then emphasise the structure in dramatic contrast the next;
- the contrast between the often very regular and geometric shape and alignment of cages or lines and the more organic shape of the landform and coastline.

As a result, water based developments are often difficult to miss. The impact of potential onshore and water based developments from significant viewpoints is another issue. Significant viewpoints include:

- views from a popular road or a route promoted as a tourist attraction;
- established settlements;
- well used vantage points;
- coastal footpaths;
- popular ferry routes; and
- sites or villages of historic, architectural or cultural importance where the setting is important for visitor experience.

The conversion of wetlands to pond farms areas can change the landscape substantially, especially if the wetland area is heavily vegetated (see figure below). Although pond walls and dykes are usually grassed to reduce erosion, they will generally maintain their man-made appearance and visual impact. Cage farms are also visually intrusive, as they are often sited in rural areas where visitors especially expect wilderness. In contrast, inter-tidal; shellfish culture using rack systems, although visually apparent, are generally judged as less imposing as they are generally viewed as a traditional land use.

Figure 7: Large Shrimp Pond Farm in Colombia

5.5.2 Determination of Evaluation Variables

Although landscape/seascape modification can have a wide variety of consequences for other land uses adjacent to a farm, the variable that has the most significance and is most easily measurable is visual impact from land or from sea. Visual magnitude assessments allows developers to consider ways to link the farm development with the surrounding landscape, often by blending the structures into the colours and textures of the vegetations patterns or by linking the siting of structures to landscape patterns.

To assess the visual impact of an aquacultural development, it is important to consider both the eye level of the viewpoint and the proximity of the viewer to the development.

The importance of the visual impact and its likely consequences or implications need to be determined in relation to significant of impact (i.e. ecological, social, economic impacts). Future evaluations of the assessments of potential visual impacts should consider the following aspects (all link to magnitude, duration, distribution of impact):

- Identify key viewpoints,
- Extent of visibility and the proximity of viewpoints to the development (zone of visual influence).
- Identification of the highest point in the development, which may be a crane or a tall building.
- Identification of how people view all elements of the development *(i.e. are people walking, with sustained views of the proposal, or are they travelling by car, with the potential development glimpsed behind landform or trees?)*
- Consideration of how views will change due to seasonal changes (e.g. lighting), such as when trees lose their leaves, or when the summer sun is at its highest.
- Identification of whether the main views of a site are from low-level vantage points or from viewpoints which allow residents and visitors to look down upon the site from above.
- Consideration whether views are mainly going to be from a distance, with the development set against a backdrop of hills or woodland, or from a nearby viewpoint.
- Consideration of how the development is going to change over time (e.g. as the weight of the shellfish increases, the original, often quite small buoys need to be replaced with larger buoys).

The magnitude could be considered as the percentage of vista change due to the aquacultural development.

The significance could be considered as the degree of change in the landscape quality and overall appearance.

The duration could be considered as the change in vista over the lifespan of the development .

The distribution could be considered as the spatial scale of effect of change in the visual assessment of a development.

5.6 DISTURBANCE

5.6.1 Characterisation of Pressure

The construction and subsequent operation of an aquaculture operation will inevitably result in human activity in and around the farming unit. The typical human activities associated with aquaculture are summarised in the table below.

Table 22: Sources of Disturbance from Aquaculture Activities

Activity	Visual intrusion	Noise		Light	Traffic		Dust
		Percussive	*Background*		*Land*	*Water*	
Facility construction	✓	✓	✓	✓	✓	✓	✓
Feeding	✓				✓	✓	✓
Maintenance	✓	✓	✓	✓	✓	✓	✓
Acoustic deterrents		✓					
Harvesting	✓		✓	✓	✓	✓	

The impact of these activities will depend upon the sensitivity of the environments concerned. Visual and background noise impacts might affect nesting and foraging habitats, whilst percussive noise from construction activities as well as acoustic deterrents (e.g. seal 'pingers' and bird scarers) may also affect marine mammals and sensitive fish e.g. those with large swim bladders. Land traffic may be limited to narrow access corridors but may restrict animal migration (e.g. amphibians), as well as cause dust and noise. Whilst bright lighting is unusual in most aquaculture production, it may become a feature during peak activities such as construction, maintenance and harvesting, and may impact nesting behaviour. For instance, sea turtle nesting behaviour is affected by bright lighting at night along coastal beaches.

Disturbance: all forms of aquaculture will have some disturbance factor. More intensive farms will have a smaller footprint but a higher level of mechanisation, resulting in higher noise levels and vehicle movement. Less intensive facilities may have lower levels of mechanisation, but more persistent human movement over a wider scale.

5.6.2 Determination of Evaluation Variables

Magnitude: although disturbance is composed of a wide variety of consequences of human activity on or around the farm (see table on page 77 for more details), the variable that has the most significance and is most easily measurable is noise. Sound emanates from construction and maintenance activities, as well as active predator control measures (i.e. AADs), transport (both vehicle and boat) as well as through routine human presence. The draft Scottish Code of Practice for Aquaculture (Federation of Scottish Aquaculture Producers, 2005) states that "Farmers should ensure that equipment that creates noise (e.g. air blowers, generators) is suitably muffled so as to prevent unacceptable disturbance to wildlife or humans".

At present there are not statutory guidelines limiting noise production from terrestrial or marine farming operations and there appears to be very little information on likely thresholds or permissible levels.

Box 2: Noise Measurement and Levels from Common Sounds

The magnitude of noise is measured in decibels (dB). Background noise consists of noises present in the environment (see table below). The measurement of the overall background noise level, adjusted with an A-weighting in decibels exceeded for 90 per cent of a given time, is expressed as the L_{A90}. In rural areas, daytime background levels may be between 38 - 42 dB but fall to below 30 dB during the night. Some noises vary in their intensity and how long they last. The equivalent continuous noise level, measured in $L_{Aeq,T}$, makes adjustments so that assessments can be made to evaluate nuisance. Although an increase of 6 dB represents a doubling of the sound and pressure, humans perceive an increase of about 10 dB in sound to be twice as loud (Environment Agency, 2002).

Noise Level dBA	Common Sounds
0 - 5	Faintest audible sound
18 - 25	TV and sound studio
20 - 30	Quiet library
40 - 45	Quiet office
55 - 60	Conversation
65 - 75	Loud radio
75 - 85	Busy street
90 - 100	Heavy lorry (7m away)
110 - 115	Punch presses
115 - 120	Riveting
140	Jet aircraft taking off 25 m away

Significance: the functional impact of noise disturbance, as well as the visual impact of human activity, is highly dependent upon the nature and position of the receiving habitat, something which will be examined in the next section.

Duration: studies on the impact of roads suggests that birds tend to habituate to continuous, low-level noises (although they may increase the strength of their calls to compensate) but will vacate areas subject to unexpected and intermittent percussive sounds. Therefore the duration of sounds may be less important to breeding and foraging birds than the frequency and magnitude.

Distribution: implementation of the EC Directive 96/61 on Integrated Pollution Prevention and Control (IPPC) in the UK through the Pollution Prevention and Control (England & Wales) Regulations 2000 requires that guidance should be sought from intensive (terrestrial) farming if 'sensitive receptors[16]' are located within 400m of the installation. For sound in air, when the distance doubles, the amplitude drops by half – which is a drop of 6 dB. Thus a movement of 1 meter away from the source means the sound pressure level will drop by 6 dB. If you move to 4 meters from the sound source, it will drop by 12 dB, 8 meters by 18 dB and so on.

5.7 PREDATOR CONTROL

5.7.1 Characterisation of Pressure

The fish and shellfish stocks held by aquaculture operations will inevitably attract the attention of wild predators. Farm operators have responded by implementing various site selection, design and management strategies to minimise the level and degree of interactions but these will continue to occur. Predator control is made more challenging when considering many predators are protected by Member State and EU legislation, especially within designed sites of conservation interest. Under Article 9 of Council Directive 79/409/EEC31 Member States can take measures to limit the impact of protected bird species in order to prevent serious damage to fisheries and water and for the protection of flora and fauna.

The different forms of predator control are described below:

Frightening devices: discourage birds from feeding, roosting or gathering at a location. Frightening techniques rely on sight and/or sound stimuli to discourage birds from remaining at a site by making the birds believe the site is dangerous for them. Success in frightening birds away depends on the number of devices used, how and where they are administered and if their use precedes the establishment of the birds' feeding habits. In general:

- Frightening techniques are most applicable for short duration problems (1 to 3 days), as birds will quickly lose their initial fear
- Frightening regimes are often started before the birds establish their regular feeding patterns
- The location of frightening devices, esp. Noise-making ones, are changed frequently;
- Long term results are usually achieved by using a combination of methods and by frequently alternating the devices used.

[16] Primarily concerns people in dwellings, hospitals, schools and similar premises, as well as people frequenting open spaces, for example, parkland. Habitats such as Special Protection Areas (SPAs) may be considered as sensitive receptors.

Acoustic Deterrent Devices (ADDs). Acoustic devices aimed at deterring aquatic mammals such as otters, mink, dolphins and seals. Three forms of ADD exist:

- Acoustic Barriers: acoustic barriers make continuous noise so as to exclude all animals from the protected farm. The philosophy is that the animals are physically separated from the fish, have no opportunity to learn how to predate farmed fish and therefore will return to eating wild fish.
- Timed conditioners: discontinuous noise-makers that produce sounds on an irregular basis. Provides negative reinforcement so that marine mammals within range do not know when they will receive a loud irritating noise but quickly learn that they will shortly receive one. By associating the protected farm with the unpleasant noise they vacate the area.
- Triggered conditioners: devices that make sounds in response to a predator. Intruding or adjacent animals, which have panicked the fish, receives an audible conditioning signal followed shortly after by the loud irritating noise. The animals quickly associates its behaviour (e.g. frightening farmed fish) with the conditioning signal. The system is a classic example of negative reinforcement as it conditions the animal's behaviour directly.

Scarecrows and predator models: utilise models or silhouettes of humans and/or predators placed in strategic locations and may be combined with frightening techniques.

Physical barriers: can consist of full enclosure which can only be practised on small, intensive sites and is often used for initial fingerling production facilities where predation pressure is high and the site area is low. Over larger, grow out sites partially-covered systems that interfere with predator feeding behaviour can be employed, such as overhead wires, lines, nets, screens, perimeter fencing and devices that discourage birds from entering the facility. Whilst many of these systems are reasonably benign, they can impact on birds, piscivorous fish and mammals. For instance, anti-predator nets suspended on the outside of fish cages may drown diving birds, seals and porpoises (Ross, 1988).

Extermination: in extreme cases, and where predators are not protected by legislation, farm operators might kill persistent predators through shooting, trapping or poisoning.

The nature and pressure of predation will vary highly depending on the culture system involved and the farm's location. Cage farms usually have a high potential for predator / stock interactions, especially during grading and harvest times when their may be blood leakage into the water. Most such farms have some form of physical anti-predator netting as well as an increased use of acoustic deterrent devices to scare away aquatic mammals. Pond farms and lagoon aquaculture, both of which tend to culture organisms in shallow water, are particularly vulnerable to avian predation and thus predator control initiatives are common.

5.7.2 Determination of Evaluation Variables

As described previously, predator control involves active and passive means of preventing wild animals from predating on farmed stock. In coastal areas, these predators can be broadly divided into (i) piscivorous birds and (ii) marine mammals (seals, otters, mink and dolphins). A significant proportion of these species are under some degree of statutory protection, so control methods usually aim to scare and rarely involved lethal force.

In terms of assessing the main variables involved, the main focus of this study

Magnitude: the magnitude of predator control efforts could be considered as the level of control effort exerted, ranging from the 'do nothing' scenario up, the installation of passive barriers, the routine use of AADs to the final step of extermination.

Significance: like noise (and a number of predator control systems use noise as a deterrent), the likely impact of predator control approaches on neighbouring species and to a lesser extent habitats is highly dependent upon their sensitivity. This in turn has strong seasonal variability, where breeding, nesting and foraging behaviour may dictate both the drivers for predation (and therefore control responses) as well as the vulnerability of the animals to the control efforts (e.g. birds reacting to gas guns). The significance of predator control efforts might be measured in the degree to which the behaviour and life strategies of both predators as well as non-predators affected by predator control mechanisms are changed. For instance, significance might be considered in terms of short-term changes, seasonal changes to life strategy and behaviour e.g. impaired breeding success and ultimately profound and long-term changes to life strategy and behaviour.

Duration: whilst passive predator control activities such as barriers are usually permanently installed, at least for vulnerable life stages (e.g. nursery), active control mechanisms may be focused during periods of perceived predator pressure. Given that most impacts will come from active measures whose effects may extend beyond the boundary of the farm (see below), this analysis will focus on underwater and terrestrial acoustic deterrent systems. In developing significance thresholds for these, the main variable chosen is the temporal impact of predator control activities on sensitive species.

Distribution: as active predator control measures are mainly achieved through sound, the distribution of pressures are similar to noise disturbance described above.

5.8 CHEMICAL INPUTS

5.8.1 Characterisation of Pressure

The aquaculture industry has adopted the use of chemicals originally developed for use in other industries sectors, most notably the agricultural sector. Many chemicals now in common use in aquaculture have never been specifically evaluated from the perspective of their effects on the aquatic environment, particularly coastal waters.

Proper selection of farm sites can substantially reduce the environmental impacts of aquaculture chemicals. Evaluation of the risks associated with aquaculture chemicals is complicated by the lack of quantitative data on their use. In particular, mechanisms need to be put in place and enforced for the registration and control of aquaculture chemicals to protect the environment and human health and to ensure growth of the aquaculture industry.

Chemicals are essential for increased and controlled production of seed in hatcheries, increased feeding efficiency, improvement of survival rates, control of pathogens and diseases and reduction in transport stress. Chemicals needs are minimal in extensive and semi-intensive culture methods.

Generally speaking, chemicals in use in aquaculture today can be grouped into three categories:

- High level of hazard (chloramphenicol, organotin molluscicides, malachite green and some organophosphates)
- To be used safety if standard precautions are followed but pose a threat to the environment.
- Environmentally benign under most situations but detrimental at specific sites

The chemicals used in coastal aquaculture includes those associated with structural materials, soil and water treatments, fertilisers, disinfectants, herbicides/algaecides, antibacterial agents, other therapeutants, pesticides, feed additives, anaesthetics and hormones.

Figure 8: Chemicals commonly used in European Aquaculture

Chemicals in use	Different compounds		Examples
Chemicals associated with structural materials	Stabilisers Pigments Antioxidants UV absorbants	Flame retardants Fungicides Disinfectants	Antifoulants on solid surfaces and on net and rope structures (i.e. cages)
Soil and water treatments	Alum EDTA Gypsum	Lime Zeolite	Flocculants to reduce turbidity in ponds To remove ammonia
Fertilisers	Organic and inorganic		To enhance production of natural food in ponds
Disinfectants	Chloramine T Formalin Hypochlorite	Iodophores Ozonation Quaternary ammonium compounds	To maintain hygiene To treat disease (little or no use in extensive systems)
Antibacterial agents	B-lactams Nitrofurans Macrolides Phenicols	4-Quinolones Rifampicin Sulphonamides Tetracyclines	Prophylactic use
Therapeutants other than antibacterials	Acriflavine Copper compounds Dimetridazole/Metronidazole Formalin Glutaraldehyde Hydrogen peroxide	Levamisole Malachite green Methylene blue Noclosamide Potassium permanganate Trifluralin (Treflan)	Antifungal agents Against Ectoparasites Protozoan infections Very specific and limited use, in general
Pesticides	Ammonia Azinphos ethyl (Gusathion) Carbaryl (Sevin) Dichlorvos Ivermectin (Ivomec) Nicotine (tobacco dust)	Organophosphates Organotin compounds Rotenone (derris root) Saponin (tea seed meal) Trichlorfon (Neguvon, Dipteres	Control predators and snails in ponds Control ectoparasitic crustacean infections in finfish culture
Herbicides/ Algaecides	Copper compounds (Aquatrine)		Very limited use in marine aquaculture
Feed additives	Astaxanthin Butylated Hydroxyanisole Butylated hydroxytoluene Canthaxantin Carotenoids	Ethoxyquin Feeding attractants Immunostimulants Vitamin C (ascorbic acid) Vitamin E	Artificial and natural pigments Vaccines and immunostimulants Mould inhibitors and antioxidants
Anaesthetics	Benzocaine Metomidate 2-phenoxyethanol	Quinaldine Tricaine methanesulphonate	To assist immobilisation of brood animals during egg and milt stripping Treatment purposes/ transport
Hormones	Growth hormone (GH) 17 a-methyltestosterone Oestradiol 17b	Ovulation-inducing drugs Serotonine	Control and induce ovulation Teleost sex control measures

Disinfectants: are used in site and equipment preparation to maintain hygiene throughout the production cycle and in some cases to treat disease.

Antifoulants: are used in coastal aquaculture throughout the world on solid surfaces and on net and rope structures. While initially developed for protection of boat hulls antifoulants are also used to treat nets containing cultured fish.

Veterinary medicines: are applied in aquaculture throughout the world. In many countries there is considerable prophylactic use. In most of Europe use is controlled by drug licensing supported by a surveillance programme to monitor compliance with limits on tissue residues. They can be applied as external treatment for fish eggs and fry, as a medicated feed and or diluted in water. These chemicals could be significant toxics to aquatic life at low concentrations, depending on species, e.g. Formalin. Farmers will ensure that the potential for contamination of the environment will be minimised when using disinfecting agents and other therapeutic agents.

Pesticides: in general terms they are used to control ectoparasitic crustacean infections in finfish culture. Some of them can produce potential effects on the health of fish farm workers, e.g. organophosphates.

Anaesthetics: are used in aquaculture to assist immobilisation of brood stock during egg and milt stripping as well as during the transport to sedate and calm animals. Anaesthetics are usually employed at very low doses so that they are no environmental risk.

Hormones: plays an important role in the aquaculture industry to control and or induce ovulation for total control of life cycles in many species. More recent innovation in the application of hormones to aquaculture include teleost sex control measures, which exhibit enhanced production characteristics.

The positive trend in recent years towards reduced use of chemicals and other artificial substances in aquaculture should be promoted and also alternative environment-friendly substances and methods of treatment, securing favourable conditions for fish should be developed.

Aquaculture chemicals were not developed specifically for aquaculture use. Environmental issues associated with residues in wastewater have been largely ignored. In particular there is little field data on the biological responses to chemical residues in receiving waters and on the concentrations of aquaculture chemicals in effluents and sediments. There is also little known with regard to the interactive effects of multiple aquaculture chemicals in relation to biological effects.

FEAP's Guiding Principles of the Code of Conduct for European Aquaculture recommends to use chemicals in a manner that does not constitute a hazard to human health and the environment and in accordance with the appropriate legislation. However there is no overall system of monitoring and control that is widely applicable throughout Europe.

The environmental concerns over the use of chemicals in the aquatic environment relate to: the direct toxicity of the compounds to non-target organisms; the development of resistance to compounds by pathogenic organisms; the prophylactic use of therapeutants and the length of time they remain active in the environment.

Many aquaculture chemists are feed additives for disease control in food fish, antibacterial antibiotic, fungus control in all food fish and eggs. Medicines may be used on prescription from a veterinarian for the therapeutic (not prophylactic) treatment of fish. Use could be intermittent (not continuous) and it is determined by the extend of the infection.

The regulation of discharges such as chemicals from cages fish farms is frequently regulated in Member States. Discharge consent conditions typically include limits on the location, maximum biomass, types and quantities of chemists which may be discharged and requirement for monitoring water and sediment quality

Although chemical treatments are used in many forms of intensive and semi-intensive aquaculture, their impacts on the wild are most commonly attributed to cage farming as it is difficult to isolate cage farming units from the main waterbody during treatment. In addition, cage-farmed fish are particularly susceptible to ectoparasites and other nekton that may required eradication. Land-based tanks and ponds may also involve the use of chemical treatments as fungicides, parasite treatments and other chemotherapeutants but there is usually a greater ability to control doses and isolate treatment areas.

5.8.2 Determination of Evaluation Variables

In order to define the impact of the chemicals used in aquaculture on the environment (non-target species and ecosystems), it is useful to define several key variables that allow us to describe the impact: magnitude, significance, duration and distribution. However, the different nature and usage of the chemical groups mentioned before makes advisable the explanation of these pressure attributes for every group considered. Given that there are no available quantitative references concerning the current use of these chemicals in aquaculture, a series of qualitative scales are proposed.

Magnitude: there is a general trend towards intensification of production methods often accompanied by greater confidence to apply chemotherapeutants, feed additives, hormones and more potent pesticides and parasiticides. Many countries engaged in coastal aquaculture have few regulatory controls and /or little documentation of the chemical used by the industry. Efforts to evaluate the risk of chemical use are hindered by the lack of quantitative data on the amounts of chemicals used. It seems the only country for which quantitative data on antibiotic use appears to be Norway. These indicate that the amounts of antibiotics used in aquaculture can vary from year-to-year. In recent years there has been a substantial reduction in the amount of antibiotic needed per require less drug per treatment.

Significance: Wild life species can suffer toxicological effects associated with the use of chemical employed in aquaculture such as bath treatment, pesticides, disinfectants and toxicants from antifouling .e.g. Organophosphate pesticide bath treatments can cause significant toxic effects larval stages of crustaceans. Antifoulants, disinfectants and antibiotics have in particular cases effect on the environment and its wild life: direct mortality and sub-lethal effects and tainting. Some chemicals appear to be relatively hazardous and on this basis their use should be restricted. Chloranphenicol and Organotin molluscicides banned in many countries where they were previously in use, are still permitted in other, being extremely toxics. Malachite green is exceptionally persistent in aquaculture products and its use is restrict in US and Europe. All organophosphates pesticides should be considered hazardous to the environment. If standard precautions are followed most of aquaculture chemicals can used safety but they can be a threat to the environment and /or human health if misused. Excessive dosage, inadequate neutralisation or dilution prior discharge could make an otherwise acceptable chemicals use, unsafe.

Duration: Many aquaculture chemicals degrade rapidly in aquatic systems. Other chemicals may persist for many months, retaining their biocidal properties. Metal-based compounds, such as the organotin molluscicides and copper-based algaecides are likely to be quite persistent in aquatic sediments.

The persistence of chemicals residues is highly dependent on the matrix and ambient environmental conditions. In general, residues in water are less likely to be long-term concern because of photodegradation and dilution to below biologically significant concentrations. Residues incorporated into sediments tend to persist for longer periods, particularly if the sediments are anaerobic as may be expected under fish cages.

The behaviour on any discharge of chemicals depends on the hydrographic conditions, bottom topography and geography of the area in question.

Predicting synergistic additive or antagonistic effects is difficult or impossible for most chemicals, including those used in aquaculture.. There is very reduce data on biological responses on the concentrations of aquaculture chemicals in effluents and sediments, with the exception of oxytetracicline in sediments beneath net cages. Several studies have assessed the impact of use of antimicrobial agents in aquaculture on the bacteria in the sediment and within fish in the local environment.

Use of pesticides, antibacterials and other therapeutants in coastal aquaculture has the potential to result in chemical residues appearing in wild fauna of the local environment. Limited data with oxytetracycline have failed to substantiate this concern but mussels near net-cages have been found to contain oxolinic acid. A number of studies have been published which demonstrate oxolinic acid residues in a range of wild fish and shellfish around a salmon net cage site persist for one or two weeks after cessation of chemotherapy in the cages. Similar results have been reported for oxytetracycline.

Distribution: When chemicals are used for preventive or treatment, a portion of them leave the farm via the effluent or in case of net-cage culture is released directly to the environment. Accumulation of associated chemical residues near the point of discharge is likely. The spatial extent of impact will depend upon dilution of the waste stream within the farm system and the rate of dilution after discharge.

The use of antimicrobial agents in aquaculture, usually administered by mixing them with feed which is dispersed in the water, which results in selective pressures in the exposed ecosystem. Uningested medicated feeds or faeces containing drug residues provide routes by which local fauna may ingest and incorporate medicaments.

Chemicals used in aquaculture can have a dispersion, dilution, distribution and concentration in the receiving water and sediment environments. Mathematical models are used to predict the concentration in sediment after treatment of a fish farm with medicines, for example. The distribution of chemicals in sediment can represent a significant distance.

5.9 PATHOGEN TRANSMISSION

5.9.1 Characterisation of Pressure

Aquaculture has been an important vector in the introduction, transfer and spread of aquatic diseases and parasites. Diseases and parasites pose a significant threat to wild populations of fish and shellfish in addition to causing economic hardship for farmers and other marine resource users in the communities where aquaculture operations are located.

The importation of exotic species for aquaculture, as well as the transport of species for culture between different facilities and regions, can lead to the introduction of pathogens that impact wild populations of fish and shellfish. Contaminated water, containers and other equipment can be also a risk for the introduction or transport of disease organisms.

Risk of pathogen transfer from aquaculture facility to the surrounding environment and other marine species populations depends greatly on the type of system that is used. Semi-closed or recirculating aquaculture systems have the least amount of potential risk for disease transfer since wastewater can be treated and the access by intermediate disease carriers can be restricted. Net pen or cages systems have the highest potential risk for disease transfer because there is no impermeable barrier between the farm and the aquatic environment. Since they are open to the environment, these systems can easily spread pathogens from farmed species to wild species and vice versa.

Intensive aquaculture provides an opportunity for the amplification of both native and exotic diseases. While aquaculture does not necessarily create diseases, the high-density living conditions in aquaculture facilities and the increase animal stress due to the overcrowding lead to outbreaks of diseases that normally occur at low levels in nature populations. In some cases, aquaculture operations have been implicated in releasing high levels of pathogens into the surrounding environment.

In the wild, the usual hosts of parasites are species that abound in the vicinity of cages feeding on waste feed and comprise the vectors for the transmission of the parasites to the farmed species. Disease rarely results from simple contact between the fish and a potential pathogen. Environmental problems, such as poor water quality or other stressors often contribute to the outbreak of disease.

Some examples of disease and parasite problems in aquaculture are:

- Salmon: Recent studies have shown that the salmon farms act as a reservoir for sea lice, a parasite that infests salmon and is easily spread from one fish to another. Salmon farms have been implicated in the spread of sea lice to wild fish; migrating young wild salmon that swim in the vicinity of salmon farms can become infected with lethal levels of sea lice. These parasites eat salmon flesh.
- Shrimp: Viral diseases have been a major problem in the shrimp farming industry. Little is known about the potential impacts of diseases on wild shrimp.
- Oysters: Exotic species used in oyster farming, introduced among various coastal regions of the world, is believed to be responsible for the spread of oyster diseases and parasites around the world.

Pathogens such *Aeromonas salmonicida* or *Vibrio anguillarum* have been reported from salmonids, gadoids and flatfish. However, these pathogens can be controlled by vaccination or chemo-therapeutants. Viral diseases are more difficult to control because there are no vaccines licensed and the control measures in the EU are largely based on movement restrictions of live fish, eggs and gametes between non-approved and approved zones or farms. Viral diseases (VHSV, IPNV, ISAV and NV) are a major concern in the diversification of aquaculture, however they can have only a limited effect on the developing industry. Other viral groups e.g. the aquarheovirus viruses may come out to be far more significant pathogens in the emerging species than the viruses commonly found in established species.

Table 23: Viral, Parasitic and Fungal Agents Affecting Aquaculture

Important diseases in Marine Aquaculture in EU	Susceptible host	Agent
Infectious Haematopoietic Necrosis (IHN)	Fish	Virus
Infectious Pancreatic Necrosis (IPN)	Fish	Virus
Viral Haemorrhagic Septicaemia (VHS)	Fish	Virus
Infectious Salmonid Anaemia (ISA)	Fish	Virus
Red Sea bream Indoviral disease (RSI)	Fish	Virus
White Spot Disease (WS)	Crustaceans	Virus
Yellowhead disease (YH)	Crustaceans	Virus
Vibriosis	Fish /Molluscs	Bacterial septicaemias
Motile Aeromonas septicaemia	Fish	Bacterial
Furunculosis	Fish	Bacterial septicaemias
Mycobacteriosis	Fish	Bacterial
Pasteurellosis	Fish	Bacterial

Important diseases in Marine Aquaculture in EU	Susceptible host	Agent
Bacterial kidney disease	Fish	Bacterial
Lactococcus	Fish	Bacterial
Brown Ring Disease (BRD)	Clams	Bacterial
Bonamiasis	Molluscs	Parasite/ Protozoan
Marteiliasis	Molluscs	Parasite/ Protozoan
Perkinsus disease	Molluscs	Parasite/ Protozoan
Neoparamoeba	Fish	Parasite/ Protozoan
Myxosomiasis	Fish	Parasite / Metazoan
Gyrodactylus salaris	Fish	Parasite/ Metazoan
Enteromyxosis	Fish	Parasite
Isopodiasis	Fish	Parasite / Crustacean
Myxosporidiasis	Fish	Parasite/ Protozoan
Microsporidiasis	Fish	Parasite/Fungi
Sea Lice	Fish	Parasite/ Crustacean
Aphanomyces spp.	Fish	Fungal

Treating infectious diseases is not always environmentally compatible. For example there are knowledge gaps in the environmental compatibility of most antiparasitic bath treatments (formalin baths, antilouse baths). Licensed antibiotics against bacterial pathogens are only few. Vaccines against *Vibriosis* and Pasteurellosis have been licensed, but protection against Pasteurellosis conferred by the available vaccines is limited and short-lived.

For many of these diseases it is not very well known their effects in the sea. Effects of drug residues or their metabolites unavoidably released in the water have not been studied. It is very difficult to assess the efficacy of a treatment in real production systems, which may be very different from that observed in lab based trials. In order to avoid environmental impact the licensing procedure for all medicines used in aquaculture must define environmental standards.

There are now many novel technologies to assist in the detection and identification of pathogens and other important molecules in aquaculture, offering proper diagnosis if disease presence is suspected. When required, only licensed or approved therapeutic agents should be used. The use and application of therapeutic agents should observe the prescribed dosage and where appropriate, withdrawal times, in order to avoid the accumulation of residues in the flesh.

The avoidance of the introduction and the spread of diseases is fundamental. Fish brought into an aquaculture system must be of good health and certified origin. Adequate precautionary measure should be taken to avoid inter-farm contamination through direct physical contact. As the fish farming industry matures and becomes more competitive on an international level, there is a growing need to increase productivity by use of genetically improved stocks. Disease hazards associated with the transfer of fertilised eggs or gametes from cultured finfish can take place. In the resulting international trade, important requirements to prevent transfer of diseases is still mostly based on a "zero-risk" approach, and there is generally a discrepancy between less stringent regulations being applied to movements inside states versus more strict regulations applying to transfers across state borders.

Farmers have the responsibility to minimise the risk of the spread of diseases beyond their farms into the ecosystem where wild fish and other farms may be affected. Diseases can be transferred by escaped fish or through ingestion of contaminated waste by wild fish. Stocking certified pathogen-free fish, reducing fish stress and filtering or ozonating effluent from pond and recirculation tank systems can minimize disease transmission. The disposal of dead fish should be done carefully and effectively, in a way that does not affect the environment negatively.

For similar reasons to chemical use above, cage farms, land-based tanks and ponds have the greatest opportunity for the transmission of disease and parasites from farmed fish to wild organisms (and vice versa). All three farming systems tend to be intensive with higher levels of stock stress that will provide conditions for these organisms to thrive. In addition, most intensive farms buy in broodstock and juveniles from elsewhere, thus increasing the risk of importing disease pathogens and parasites.

5.9.2 Determination of Evaluation Variables

As previously described, farmed fish and shellfish are quite vulnerable to different pathogens that cause diseases that can be transmitted to wild stocks and in some cases to the consumer. Those diseases can represent a significant economic losses for fish farms but may be even more significant for wild fauna.

Given that there are no available quantitative references concerning the effects or dynamics of these diseases and parasites, a series of qualitative scales are proposed.

Magnitude: Production costs are increased by fish disease outbreaks because of the investment lost in dead fish, cost of treatment and decreased growth during convalescence. Disease problems are less observable in nature because sick animals are quickly removed from the population by predators. In addition, fish are much less crowded in nature systems than in captivity. It has been shown that stressed fish will produce certain hormones which suppress the immune system. This can make farms act as disease amplifiers for a pathogen (i.e., salmon farms). The magnitude can be assessed on whether the pathogen is present within the systems, whether it is exerting clinical symptoms and as to whether the pathogen is impacting wild populations.

Significance: There are two broad categories of disease that affect fish, infectious and non-infectious diseases. Infectious are caused by pathogenic organisms present in the environment or carried by other fish. There are contagious diseases and some type of treatment may be necessary to control the disease outbreak. Non-infectious diseases are in general categorized as environmental, nutritional or genetic. These problems are often corrected by changing management practices.

Parasites and bacteria may be of minimal significance under natural conditions but can cause substantial problems when animals are crowded and stressed under culture conditions. The significance depends upon the lethal and sub-lethal effects of the pathogen on individuals and larger populations.

Duration: There are very infectious diseases that can be transmitted from one fish to another through sea water where the pathogen can be very long-lived, finding it in sediments under cages or in seawater for more than year. Many of parasitic diseases can be easy controlled by licensed medication but others there are not treatment. Restrictions in the movement of live material between countries must be enforced because pathogens are still a significant potential threat. The duration of a pathogen's impact is dictated by the nature of the pathogen itself (its vulnerability to treatment and natural exposure as well as its ability to form hardy spores) as well as the degree of re-infection that might come form external inputs, especially from wild populations.

Distribution: Cages open to the ocean can spread diseases to wild fish and another fish farms. Direct fish to fish transmission with a rapid spreading of disease can happen in certain farms (i.e., turbot enteromyxosis), while some diseases are transferred by a intermediary host.

There are cases where pathogens were transferred from one country to another where populations lacking resistance, this resulted in the extinction of many wild populations. In any case, although aquaculture represents a possible method of transmission it is thought that unintentional transfer by anglers represents a more significant risk.

There is currently very little knowledge on the distribution and abundance of disease organisms in aquatic ecosystems making it difficult to know if diseases observed in aquaculture are native to the area or if they have been introduced. Further monitoring is required to determine the degree to which transfer is occurring and whether it has significance for wild populations.

5.10 INTER-BREEDING WITH WILD ORGANISMS

5.10.1 Characterisation of Pressure

Aquaculture is one of the causes of loss of fish biodiversity through the massive, continuous, unintentional releases of artificially cultured individuals over large areas (Naylor *et al.* 2005). Escapes occur both during routine handling and as a result of large-scale accidents. In the native range, an estimated two million farm salmon escape each year into the North Atlantic (Schiermeier 2003). Roughly 20% to 40% of the Atlantic salmon caught in the fisheries of the North Atlantic high seas (off the Faroes) between 1989 and 1996 was of farmed origin (Hansen *et al.* 1999). Farm salmon represent on average 11% to 35% of the "wild" spawning populations in Norway, with some populations exceeding 80% (Fiske *et al.* 2001).

The principal species of marine aquaculture in Europe are Atlantic salmon (*Salmo salar* – itself an Natura 2000 Annex II species), sea bass (*Dicentrarchus labrax*) and sea bream (*Sparus auratus*). These are also the only species for which the problem of interbreeding has been studied. For Atlantic salmon and sea bass, a substantial part of total genetic variation is partitioned at the geographical population level. In the case of sea bream, gene flow across the Azores/Mediterranean scale appears to be extensive and population structuring is not detected. For Atlantic salmon and sea bass, natural population structure is at risk from genetic interaction with escaped aquaculture conspecifics. Therefore, the locally adaptive features of populations are at risk from interbreeding with non-local aquaculture fish. Atlantic salmon is the main European aquaculture species and its population genetics and ecology have been well-studied. A general case regarding genetic interactions can be based on the information available for salmon and extended to cover other species, in the appropriate context (Youngson *et al.* 2001).

The potential consequences of farmed fish escapes can be divided in the two broad categories : genetic interactions (i.e. interbreeding) and direct competition. For the purposes of this section, genetic interactions are the main topic of interest but direct competition may also have consequences for the viability of a wild population ad will, therefore, be mentioned briefly.

Genetic interactions

Farmed fish differ genetically from wild fish for three reasons :

1. farmed fish are often derived from non-indigenous sources and are likely to differ genetically from wild populations;
2. farmed populations are sometimes established using few fish and have small genetically-effective population sizes that can result in random genetic changes;
3. furthermore, human-engineered breeding patterns and the culture environment create intentional/unintentional selection which can lead to domestication over a few generations.

Various studies have been conducted with the aim of testing for genetic response to domestication in fitness related traits of farmed salmon and hybrids. The results are summarised in the table overleaf.

Table 24: Differences in Fitness-related Genetic Traits between Farm and Wild Salmon

Characteristic	Farmed Salmon	Wild Salmon	Comments
Morphology	Farmed fry had deeper, robust bodies; less streamlined bodies; smaller rayed fins including dorsal fin width and anal, pelvic and pectoral fin lengths.	Smaller in size with streamlined bodies, V-shaped caudal fin	Results indicate that intentional/unintentional selection during generations of domestication generated divergence in morphology
Aggression	Higher mean frequency of overt aggressive acts	Wild salmon dominated during contests in stream-like environment	Results suggest that the expression of aggression and dominance are due to genetic and environmentally induced changes. Hybrids will be more aggressive.
Predator response	Risk prone behaviour	Greater response to predation risk	Results show a relaxation of selection against predator-vulnerable phenotypes in culture facilities are absent. Hybrids will show a risk prone behaviour.
Breeding behaviour	Females: - lower number of nests, -bred for a shorter period -retained a greater n° of unspawned eggs -greater nest destruction -lower nest construction in absence of wild salmon - lower egg survival - higher hybridization between farmed females and wild males Males: -failed in entering nests to fertilize eggs -lower courting behaviour	Females: - larger number of nests - bred for a longer period - low nest destruction - greater egg survival - lower hybridization between wild females and farmed males Males: -greater fertilization of eggs - greater courting behaviour and aggressiveness	Results show that captive breeding and artificial culture reduce natural reproductive ability of fish.
Reproductive success	Females only had a reproductive success of 20-40 % if compared to their wild counterparts Males attained 1-3% of reproductive success	Wild females have a greater reproductive success with wild fish. Wild males have a greater reproductive success with both wild and farmed females	Results show that reproductive success is lower in farmed salmon. However, farmed females and wild males have a high reproductive success. This causes a great risk as the gene flow from the cultured females is higher than from cultured males to the wild populations
Growth in Hatchery	Farmed salmon have a higher growth rate in the absence of interpopulation competition	Wild salmon had a lower growth rate, however they had a higher growth performance in the presence of interpopulation competition.	The higher growth rate of farmed salmon is a consequence of genetic differences in consumption rate, metabolism, assimilation efficiency or a combination of all three.
Performance in semi-natural environment	Farmed salmon have shown to have both a lower and higher growth rate in the presence of interpopulation competition.	Wild salmon have both a lower and higher growth rate in the presence of interpopulation competition.	The results suggest that differing genetic origins of the two populations prior to culturing may have as much to do with the outcome of competition and growth as the effect of culturing itself.
Parr maturity and smolting	Farmed salmon had a higher smolting rate, but showed a lower incidence of parr maturity.	Wild salmon had a lower smolting rate, but showed a higher incidence of parr maturity.	The result suggests that the differences in smolting between the two groups are related to hatchery growth performance. Whereas parr maturity is due to directed selection for delayed sea-age maturation.

Source : Einum & Fleming 1997 a , b

However, inter-breeding between unrelated or distantly related individuals (cross-breeding) that occur by chance in small populations or by assortative mating in large populations have been proved to produce the following direct impacts :

Genetic Alteration (loss of gene pools) : interbreeding between cultured and wild populations leads to *introgression* (i.e. incorporation of genes from one population into another leading to the breakdown of co-adapted gene complexes and thus to homogenization of the genetic structure). This leads to the irreversible loss of genetic heterogeneity which reduces the adaptive capacity of the fish to environmental change. The detrimental effects of introgression are linked to the extent of genetic differentiation of farmed from wild populations and to the potential reproductive success of farmed fish when they invade wild populations.

Fleming *et al* (2000) tested the salmon gene flow from farm to native fish to determine the magnitude of its evolutionary force. The experiment based itself on the hypothesis that 55% of the present salmon population was made up of escaped salmon. The gene flow which occurred during this study indicated that the farm escapees in the experimental spawning population contributed 19% of the genes to adult fish one generation later, which is considered a high evolutionary force. In these conditions, the genetic difference between the donor (farm) and the recipient (wild) population is halved every 3.3 generations, although this will also depend upon the fitness of the hybrids and backcrosses during following generations. The shorter generation time of the hybrids would also tend to increase the rate of introgression. With an estimated 55% of escaped farm salmon and the mentioned gene flow the native population would be eventually composed of individuals descended from escaped fish (Fleming *et al.* 2000).

Fitness reduction : when escaped farmed fish breed successfully and hybridize with wild fish the other effect which is likely to be produced is fitness reduction in offspring. In recent studies conducted in Ireland concerning a farm release of salmon results showed that the lifetime success of hybrids was only 27 to 89% as high if compared to their wild counterparts and 70% of the embryos in the second generation died (McGunnity *et al.* 2003).

The extent of reduction in fitness of the wild population depends on many factors, including availability of unoccupied juvenile habitat, number of wild/farm/hybrid fish, reproductive success and natural selection. Although natural selection should lead to the re-adaptation of the negative domestic traits, the fact that farm escapes are repetitive, often resulting in annual intrusions, means that such reductions in fitness are cumulative. Therefore, extensive inter-breeding between farm and wild fish may eventually lead to the overall reduction in the population size or drive vulnerable populations to extinction (Naylor *et al.* 2005).

Farm escapees can also breed with wild salmon of a different species. Interspecific hybridization occurs naturally at low rates between Atlantic salmon and brown trout (*Salmo trutta*) (Youngson *et al.* 1993). An increase in the rate of hybridization between these species in Scotland and Norway shows associations with the presence of escaped farm salmon (Hindar and Balstad 1994). The average proportion of interspecific hybrids is low (1% or less), but reaches 10% or more in some rivers. Interspecific hybrids survive well but are largely sterile, and thus may lower the productivity of local populations. Lowered productivity is of special concern where local populations are endangered.

According to an earlier review (Hindar *et al.* 1991), later supported by the experimental evidence mentioned above, two broad conclusions can be derived from the studies on the genetic consequences of inter-breeding :

1. the genetic effects of intentionally or accidentally released salmonids on natural populations are often unpredictable and may vary from no detectable effect to complete introgression or displacement.

2. when genetic effects on performance traits (e.g., survival in fresh water and seawater) have been detected, they appear always to be negative in comparison with the traits of unaffected native populations.

It therefore should be noted that detailed, long-term studies are necessary in order to determine, among other things, the rate of "invasion" of "unfit" genes into the wild gene pool, that will have a significant impact (Christos Theophilou, DG Fish, pers. comm.).

Direct competition

Escaped fish may compete directly with wild individuals for space, food or mates causing potential impacts on the viability of the receiving population. According to recent literature on the topic both escapes of adults from sea cages and escapes of juveniles from freshwater hatcheries have the potential to affect population density, at least initially, and can alter the frequency of competitive interactions, levels of food availability, or functional responses of predators (Naylor *et al.* 2005).

The potential for competition in rivers is significant because the diet and habitat choice of farm and hybrid juveniles overlap with those of their wild conspecifics (McGinnity *et al.* 1997, 2003, Fleming *et al.* 2000). Farm juveniles typically outgrow wild juveniles, even in nature, reflecting artificial selection for growth (Fleming *et al.* 2002). Farm offspring thus have a size advantage and, potentially, a competitive edge over wild juveniles.

As mentioned above, there are also clear and consistent behavioural differences between farm and wild juveniles that are genetically based, including greater aggression and risk-taking by farm juveniles. Territorial and social dominance is widespread in wild salmonid populations, therefore the displacement of native fish by larger, more aggressive farm and hybrid fish can also result in shifts of wild counterparts to poorer habitats, increasing mortality (McGinnity *et al.* 1997, 2003). The outcome of such interactions has been tested in a recent experimental release study, which showed that the productivity of the native juvenile salmon population was depressed by more than 30% in the presence of farm and hybrid juveniles (Fleming *et al.* 2000).

Little is known about competitive interactions in the marine environment. The presence of large numbers of escaped farm salmon in coastal ecosystems is likely to increase competition for available resources as introduced fish consume wild food items and occupy space (Naylor *et al.* 2005).

5.10.2 Determination of Evaluation Variables

The inter-breeding risks that escaped farm fish pose are a function of various factors, some of which have not yet been completely understood :

- probability of escape
- magnitude of each escape event (number of escapees)
- number of wild male/farmed female reproductions (as they cause greater gene flow)
- n° of escapes in springtime (as escapees have a greater survival rate)
- early life history of hybrid offspring, and
- reproductive success (i.e. capacity to breed successfully in the wild) of farmed and hybrid fish.

The probability of escape and the magnitude of each escape event depend on the production system and its characteristics. Sea cages are particularly prone to tearing from storms, human error, predators or other causes, resulting in the mass escape of fish annually. The Norwegian Directorate of Fisheries collects the official escape numbers in Norway every year.

The following table lists the various causes to which the escapes of salmon farmed in sea cages where attributed in 2003, with a total of 435,000 escapes (WWF, 2005).

Figure 9: Causes for escapes of farmed fish in Norway (%) of total escaped fish (2003)

Escapes Causes	% of total
Construction failure	50.3%
Collision	42.7%
Other	5.5%
Hauling	0.6%
Propeller injury, seine	0.5%
Flotsam	0.3%
Handling	0.1%
Predators	0.0%

Source: WWF, 2005

It is clear that collisions with boats or other objects and failure of the cages account for more then 90% of escapes. In particular, escapes from cage farms owing to failures are mainly due to:

- poor maintenance of nets and other equipment
- inappropriate specification of containment equipment for the exposure characteristics of the site

Although there have been improvements in containment technology and husbandry practice, the absolute number of escapes may remain high as a consequence of expansions in the industry. In general, cages in a sheltered area and in an enclosed sea, such as the Mediterranean, are likely to be less prone to damage than cages far off-shore or in the Atlantic.

Magnitude : magnitude of inter-breeding can be defined on the basis of the proportion of farmed fish escaped (in number) to the known or estimated size of the wild population (in number). This proportion can be considered as a proxy to the extent of interbreeding between farmed and wild populations which is much more complex to estimate.

As an example, the Norwegian Directorate of Nature Management provides statistics on the presence of escaped farmed fish in coastal areas and salmon rivers since 1989. For the salmon rivers, the average percentage of escaped fish in 2003 was 13%. However, over half of the monitored rivers were impacted with farmed fish, and some rivers had up to 48% farmed fish in the spawning stock (WWF 2005).

Significance : As mentioned, successful interbreeding (i.e. reproductive success) between farm escapes and wild fish depends on various factors (i.e. number of escaped fish, sex of fish escaped etc.). However, there is no clear proportional relationship between the degree of interbreeding occurred and the significance of interbreeding for the fitness of the wild population, because a variety of other factors are involved (e.g. availability of unoccupied juvenile habitat, number of wild/farm/hybrid fish, reproductive success and natural selection). In other words, there might be a very high level of interbreeding with very limited loss of fitness for the recipient wild population and vice-versa. The main variable involved is the genetic differentiation between farmed and wild populations. Nevertheless, while the detrimental effects of introgression generally increase with genetic differentiation between farmed and wild populations, the rates of introgression are likely to decrease complicating matters further. Regardless of the variables involved, the significance of interbreeding may be negligible or, in the worst of cases, eventually lead to the extinction of the fish species.

The IUCN internationally recognized guidelines for the determination of the threatened species categories indicates a method for highlighting those species under a high extinction risk (IUCN 1994). This method can be used to evaluate the significance of interbreeding. Following IUCN classification the first criteria is an observed, estimated, inferred or suspected reduction of the population over the last 10 years or three generations, whichever is the longer, based on any of the following :

a) direct observation

b) an index of abundance appropriate for the taxon

c) a decline in area of occupancy, extent of occurrence and/or quality of habitat

d) actual or potential levels of exploitation

In particular, the IUCN classification for critically endangered, endangered and vulnerable taxon uses the following thresholds based on the estimated size of a population :

- **Vulnerable** : observed reduction of 20% of the population over the last 10 yrs or 3 generations (whichever is the longest)
- **Endangered** : observed reduction of 50% of the population over the last 10 yrs or 3 generations (whichever is the longest)
- **Critically Endangered** : observed reduction of 80% of the population over the last 10 yrs or 3 generations (whichever is the longest)

Based on recent scientific evidence, it can be assumed that when more than 20% of the spawning stock consists of escaped farmed salmonids, it can have an impact on the wild stock. When almost half the salmon in the river is of farmed origin, this is likely to have a considerable negative impact. Based on this assumption the Norwegian Directorate of Nature Management, has classified salmon rivers according to their likely level of threat to wild populations. On this basis, 7% of the rivers can be classified as directly threatened by the large amount of farmed fish in the spawning stock, meaning that more than 45% of the fish in these rivers is of farmed origin[17] (DN 2004).

Duration : if the number of escapes is high and repeated the one-way gene flow rate could be of such a significance to bring to the extinction of the fish species. Therefore, one of the most important elements determining the extent of interbreeding and its significance is the frequency of escapes from farms. Clearly, the more frequent the escapes, the higher the risk of lasting impacts on the natural populations. In particular, it appears that escaped fish during springtime have a greater survival rate and increased opportunity for breeding with wild fish (Fleming *et al.* 2000). Apparently, no study has defined a clear relationship between the frequency of escapes and the effects on the wild population because too many variables can effect the extent of interbreeding and its significance.

Distribution : Extent of occurrence and area of occupancy are foreseen by the IUCN guidelines for the determination of threatened species. Extent of occurrence is defined as the area contained within the shortest continuous imaginary boundary which can be drawn to encompass all the known, inferred or projected sites of present occurrence of a taxon, excluding cases of vagrancy. This measure may exclude discontinuities or disjunctions within the overall distributions of taxa (e.g., large areas of obviously unsuitable habitat). Area of occupancy is defined as the area within its extent of occurrence which is occupied by a taxon, excluding cases of vagrancy. The measure reflects the fact that a taxon will not usually occur throughout the area

[17] The Norwegian Directorate of Nature Management classifies rivers on the basis of their farmed/wild ratio in one of the following categories : threatened (above 45%), heavily impacted (21 – 45%), impacted (6 – 20%) and not impacted (less than 6 %).

of its extent of occurrence, which may, for example, contain unsuitable habitats. The area of occupancy is the smallest area essential at any stage to the survival of existing populations of a taxon (e.g. colonial nesting sites, feeding sites for migratory taxa). The IUCN guidelines also offer some thresholds so as to determine when a species is to be classified as critically endangered, endangered, and vulnerable (IUCN 1994).

The effects of inter-breeding will be felt at a wider spatial scale depending on the distribution of the wild population, the biological characteristics of the species (i.e. migrations behaviour and life-cycle), the breeding success of the farmed fish and time of exposure (i.e. number of generations in which hybridisation has occurred). In terms of potential impact, we can say that the smaller the area of occupancy of wild fish the higher the potential impact of interbreeding on that population. As mentioned above, for Atlantic salmon and sea bass, a substantial part of their total genetic variation is partitioned at the geographical population level. Therefore, the adaptive features of their local populations are likely to be at higher risk from interbreeding with non-local aquaculture fish (Youngson *et al.* 2001).

5.11 INTRODUCTION OF ALIEN SPECIES

5.11.1 Characterisation of Pressure

Alien species are, with respect to a particular ecosystem, any species, including its seeds, eggs, spores or other biological material capable of propagating that species, which is not native to that ecosystem. *Invasive Species* are those species whose introduction does, or is likely to cause, economic and environmental harm or harm to human health (US 1999). Therefore, not all alien species are invasive because:

- not all alien species introduced into a new ecosystem are able to adopt and reproduce in the new conditions
- not all alien species capable of adapting cause environmental or economic harm or, in other words, become pests.

Most organisms introduced in a new environment will probably fail to settle, however studies have shown that approximately 10% of introduced alien species will survive and succeed in reproducing. Of these, only 10% might cause significant ecological changes, but knowledge is lacking as to what has been altered. Any species without a major role in its natural environment can suddenly become a plague in another.

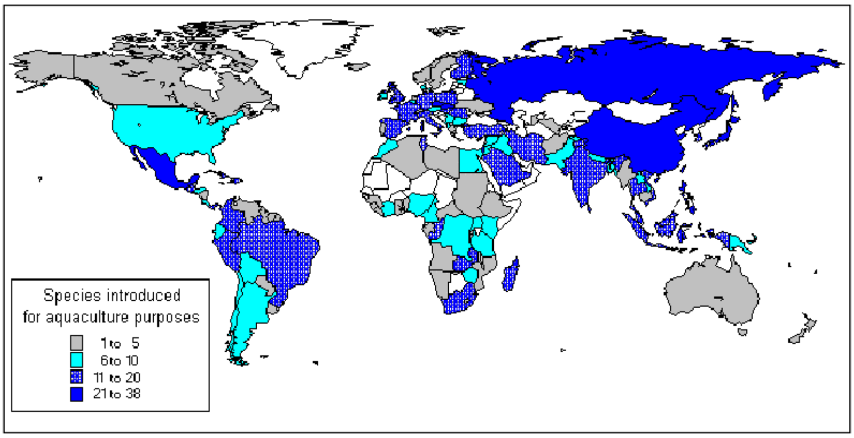
The major impacts posed by alien species on ecosystem, habitats and species are a consequence of the fact that they can establish, invade and change the new habitats to the detriment of the native species. The establishment of alien species in new regions does not create enrichment for the region, but tends to uniform biodiversity by causing loss of endemic, unique and native species and ecosystems. According to the United Nations Environment Program (UNEP) invasive species are second only to habitat loss as the major threat to global biodiversity.

Introductions can be <u>intentional</u> if they are specifically intended to generate income (i.e. aquaculture), provide employment, serve as biological control of pests or supplement dwindling native populations (i.e. re-stocking). <u>Unintentional</u> introductions include fouling organisms, removal of natural barriers, aquarium fish trade or ballast waters.

The introduction of alien fishes into countries outside their range is a relatively recent phenomenon showing peak periods towards the end of the 19th century and in the 1960s and 1970s, although some species are believed to date from Roman and Medieval times (EC 2001).

Aquaculture is the reason of introduction in 38.7% of the records in the FAO Database on the Introductions of Aquatic Species (FAO DIAS). The figure below shows the extent and relative importance of the introduction of species (marine and freshwater) for aquaculture purposes worldwide. The near inevitability of escapes from aquaculture facilities has led to the recommendation that introductions of species for aquaculture should be considered an introduction to the wild, even if the facility is considered a closed system (FAO 1995).

Figure 10: Number of species introduced for aquaculture purposes

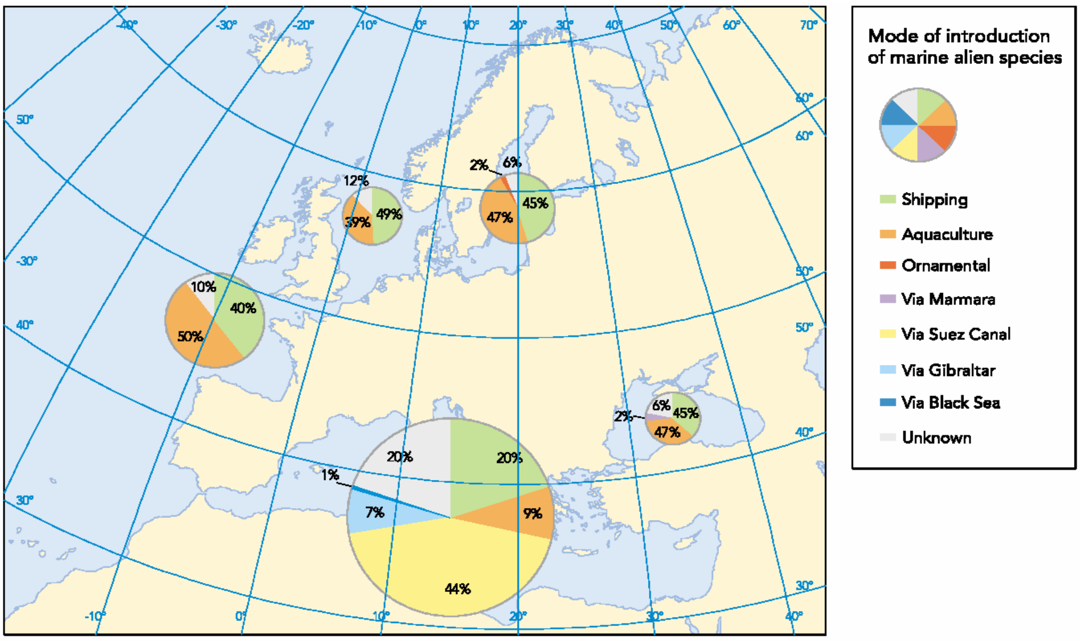


Source: FAO DIAS 2004

Alien fishes have been intentionally introduced in Europe for a variety of reasons. However, aquaculture purposes have always comprised a significant proportion of the total and have increased in importance, accounting for 50% of all introductions made in some areas. In particular, about 660 alien marine species have arrived in European coastal waters through shipping, aquaculture and other man-made activities. The Mediterranean Basin has received about 500 such species, mostly via the Suez Canal (opened in 1869), while less than a hundred are known to have arrived in the Atlantic, North Sea and Baltic Sea coasts. The rate of arrival has shown some signs of decreasing over the last two decades in the Mediterranean, Baltic, Black and North Seas (EEA 2003).

The primary mode of arrival in European seas is shipping (154 species) with aquaculture coming next (124 species). The arrival in the Atlantic Ocean of alien macroalgae and macrobenthic organisms appears to have accompanied stocks imported for aquaculture (see Figure below).

Figure 11: Mode of introduction of alien species in European coastal waters



Source : EEA 2003

The table below summarises the invasive species intentionally or unintentionally introduced as a result of aquaculture activities in Europe. Many others have been introduced intentionally but they have not turned into invasive species (ICES 1999).

Table 25: Invasive species with known impact on the receiving ecosystems introduced as a results of aquaculture activities in Europe

Species Name	Known Impacts	Invasion pathways
Rainbow Trout (*Oncorhynchus mykiss*)	Hybridisation, disease transmission, predation and competition with native species. In some cases the introduction of the rainbow trout has caused the virtual extinction of native species of fish through direct predation or competition for food and has negatively impacted populations of amphibians and invertebrates.	Introduced intentionally as an aquaculture species or sportfish for angling
Tilapia (*Oreochromis spp.*)	Tilapia is the common name applied to three genera of fish in the family Cichlidae. These include over 70 species of fish, at least eight of which are used for aquaculture. Tilapia belong to a family of fish known as cichlids, among which most African members are mouth brooders. The cage culturing of tilapia results in a reduction of water quality in the surrounding environment, which is particularly worrying when near ecologically important areas. The unavoidable escape and establishment of wild tilapia from cages has sometimes resulted in other serious problems, such as the decline of culturally valued native fish species and the alteration of natural benthic communities.	Introduced intentionally as an aquaculture species
Japanese Carpet Shell (*Ruditapes philippinarum*)	The impacts of *R. philippinarum* are not completely known but there has been a suggestion that these species might have competed with the local species of shell in the Adriatic sea causing its virtual extinction.	Introduced intentionally for aquaculture purposes in the Mediterranean (France, Spain and Italy)
Rapa Whelk (*Rapana venosa*)	*R. venosa* is an active predator of epifaunal bivalves, and its proliferation is a serious limitation to natural and cultivated populations of oysters and mussels. *R. venosa* are credited with drastic declines in Black Sea bivalve populations including almost complete extinction of the Gudaut oyster bank.	Egg masses may have been transported with products of marine farming
Pacific Oyster *(Crossostrea gigas)*	*C. gigas* is well known for its tendency to colonize areas of coastline many kilometres away from its parent organisms. Spat have been documented spreading up to 1,300 km on ocean currents. Once established, they have the potential to smother other marine life, such as scallops, destroying habitat and causing eutrophication that affects water quality. They pose a direct threat to human safety because of their propensity to cut feet and shoes with their sharp shells. There is some concern that the indigenous European oyster (*Ostrea edulis*) has become a threatened species partly as a result of *C. gigas* introduction, but more recent accounts on the subject seem to prove that overexploitation by oyster fishery since the 18th century exterminated European oyster populations. Since 1964, the Pacific oyster *C. gigas* has been imported for cultivation to several places in Northern Europe, the Pacific *C. gigas* is now firmly established in the wild. Due to the higher growth rate and the larger size of oysters, blue mussels are eventually overgrown and killed.	Introduced intentionally as a commercial species of importance for aquaculture in UK and France. It spreads through placement of hatchery-produced seed.

Species Name	Known Impacts	Invasion pathways
Japanese Kelp (*Undaria pinnatifida*)	It is an opportunistic weed which forms dense forests, resulting in competition for light and space which may lead to the exclusion or displacement of native plant and animal species. The impacts of *Undaria pinnatifida* are not well understood and are likely to vary considerably depending on the location. Undaria can change the structure of ecosystems, especially in areas where native seaweeds are absent. NIMPIS, 2002 states that *U. pinnatifida* has the potential to become a problem for marine farms by increasing labour and harvesting costs due to fouling problems on fin fish cages, oyster racks, scallop bags and mussel ropes. Heavy fouling may also restrict water flow through cages.	It has been accidentally introduced to the Mediterranean Sea (France, Italy). It was deliberately introduced into the North Atlantic, to Brittany for commercial exploitation, then was recorded in natural communities in France, Britain, Spain. The potential for accidental translocation of *Undaria* through aquaculture has been suggested
Dead man's fingers *(Codium fragile spp tomentosoides)*	The invasive success of *C. fragile ssp. tomentosoides* can be attributed to various characteristics of the alga's life history and physiological ecology. This species exhibits various modes of reproduction (sexually, parthenogentically, and vegetatively). Water currents can carry this species over long distances introducing it to new locations. *C. fragile* is also tolerant of a variety of salinity and water temperature levels. It also thrives in sheltered habitats, which facilitate human mediated dispersal. *C. fragile ssp. tomentosoides* has serious economic implications for aquaculture industries. Indeed, the tendency of this species to overgrow and smother oyster beds has earned it the nickname 'oyster thief'. There are several direct and direct effects of this attachment; these include: smothering mussels and scallops by preventing opening of the valves, clogging scallop dredges, and interfering with the collecting of clams.	*C. fragile* dispersal was probably aided by human activities such as boating or shellfish aquaculture. *C. fragile* has been known to be introduced through oysters. The alga arrives attached to the oysters.
Naked dinoflagellate *(Gymnodinium catenatum)*	Toxins (saxitoxins and gonyautoxins) produced by *G. catenatum* can cause Paralytic Shellfish Poisoning (PSP). Studies show that most outbreaks are produced at temperatures lower than 25°C. The toxins are released when *G. catenatum* cells are eaten by shellfish, such as oysters, mussels and scallops, making them poisonous to consume. In extreme cases, PSP causes muscular paralysis, respiratory difficulties, and can lead to death. *G. catenatum* also poses threats to wild and aquaculture shellfish industries, due to economic losses resulting from farm closures. Mass mortality has occurred at shrimp farms that have been affected by blooms of *G. catenatum*.	Found in waters around Western Europe including the Mediterranean. Cysts of *G. catenatum* can be accidentally translocated through aquaculture and fisheries activities, such as in oyster cages or on mussel ropes.
Leathery sea squirt *(Styela clava)*	When *S. clava* populations explode they often out compete many native species for food. *S. clava* can reach densities of 500-1500 individuals per square meter. These extreme densities can have negative impacts on native and aquaculture species through competition for space and food as well as predation of larvae from the water column. *S. clava* invasiveness is enhanced through its hardy nature, capable of withstanding salinity changes and temperature fluctuations. It can also occur as fouling on vessels, aquaculture and fishing equipment and other artificial structures.	Found all over Europe. Possible methods of introduction include being transferred on oyster shells.
American limpet or Oyster pest *(Crepidula fornicata)*	*C. fornicata* has been reported to alter sediment characteristics (by removing a huge volume of suspended organic material from the water column, and depositing that filtered material on the bottom as pseudofaeces). It is also reported to decrease the abundance of certain suprabenthic species (such as mysids). It is considered a pest on commercial oyster beds, competing for space and food. Other studies, show that the presence of C. fornicata does not affect the benthic community. *C. fornicata* seems to be one of many reasons for the decline in local maerl bed habitats in Britain. Negative effect of this invasive species on the density of young-of-the-year sole *Solea solea* in coastal nursery areas of the Bay of Biscay (France) have been shown.	*C. fornicata* was introduced in association with imported American oysters *Crassostrea virginica*. It is widespread in The Netherlands, France, Italy, United Kingdom, Denmark, Norway, Sweden and Spain.

Species Name	Known Impacts	Invasion pathways
Wireweed (*Sargassum muticum*)	Numerous impacts caused by *S. muticum* are reported : 1) Physical hindrance of small boats with outboard engines of up to 20 h.p.; 2) Clogging of intake pipes, both of boats and industrial installations; 3) Floating mats of *S. muticum* foul commercial fishing lines and nets; 4) Floating debris tends to be concentrated by buoyant fronds forming floating mats and creating an eyesore; 5) Large mats of weeds are eventually cast up on shores and cause problems when rotting, i.e. producing offensive smells on resort beaches; 6) The extensive development of *Sargassum* populations on oyster beds hinders the growth and harvesting of the shellfish; 7) Large dense stands of *Sargassum* may cause loss in amenity and recreational use of water areas, e.g. swimming, skiing, sail boarding, dinghy sailing and fishing; 8) The presence of dense *Sargassum* stands may affect species diversity of indigenous marine fauna and flora in intertidal pools and the shallow subtidal region.	S. muticum is spread from Norway to Spain on the Atlantic coast and has been recorded in the Mediterranean (France, Spain and Italy). It might be introduced through shipments of Japanese oysters that were imported for aquaculture.

Sources : IUCN-ISSG Global Invasive Species Database (www.issg.org/database) - FAO Database on Introduction of Aquatic Species (www.fao.org/figis)

Long-term impacts from the introduction of alien species can be summarized in the following points:

Habitat alterations: alterations in the physical or chemical characteristics of a habitat can be caused by any kind of exotic organism by its use of a specific resource (e.g. trace elements, oxygen, food), by its behaviour or by its metabolism. For example, habitat alteration by alien fish species mainly involve the displacement of aquatic vegetation and the degradation of water quality. The former can be brought about by the consumption of plant material by herbivorous species, by the uprooting of macrophytes through digging for food or nesting sites, and by roiling and organic enrichment which increases turbidity, thus reducing light penetration and photosynthesis. Modification of aquatic plant communities can significantly affect native fishes and other animals.

Trophic alteration: the use of exotic species can alter trophic relationships in aquatic communities in different ways, all of which may cause changes in the population of the native species. Firstly their presence may significantly increase the amount of prey available to native predators. Secondly, the feeding habits of exotic species can reduce the amount of forage available to native species through a dietary overlap. Thirdly, exotic predatory fishes can profoundly affect the population dynamics of indigenous prey species. The reduction in the population of autochthonous species is sometimes difficult to attribute with certainty to predation or competition from an exotic and occasionally both influences may act in concert. Salmonids have one of the worst records for damaging native species of fish. Rainbow trout (*Oncorhynchus mykiss*) has been partly responsible for the reduction of indigenous salmonids in Lake Ohrid in former Yugoslavia.

Spatial alteration: spatial alteration occurs when introduced exotic species compete and thus displace native species from their natural habitat (i.e. competitive displacement). Recent studies have found that larger farmed fish and hybrids dominate and displace wild salmon parr forcing them to migrate downstream looking for suitable unoccupied habitats (McGinnity *et al* 1997).

Another serious effect concerns competition for spawning habitat. Exotic fish often destroy redds and eggs of wild fish and other organisms, thus seriously affecting their populations. This is thought to be one of the major threats caused by the use of exotic species although few studies have yet quantified its effect.

Introduction of parasites and diseases: the use of exotic species has also lead to increasing disease outbreaks which have proliferated possible disease transmission routes in the environment and decreased the immunity of wild fish to disease. Dense aggregations of farmed fish are an ideal breeding ground for diseases and parasites. Furthermore, stress placed on fish resulting from high density and intensive cultivation is often sufficient to allow pathogens to take hold and form disease reservoirs.

Escaped exotic species are a potential vector for spreading parasites and diseases to wild fish. This can be the introduction of alien parasites and diseases such as Gyrodactylus salaries and furunculosis, or the spread of naturally occurring parasites like salmon lice (*Lepeophteirus salmonis*, *Caligus* spp.). Salmon lice can also transfer virulent infectious salmon anaemia (ISA) between fish. Other diseases that spread amongst fish are the infectious pancreatic necrosis (IPN) and the infectious haematopoietic necrosis (IHN) which has been spread from steelhead to wild salmon populations.

For the purposes of this report this particular aspect has been considered separately as it is recognised as a particularly relevant problem for the aquaculture sector.

Interbreeding: as mentioned, interbreeding between introduced alien species and wild fish involves genetic risks, which vary with the genetic characteristics of each population, the proportion of introduced to native individuals and the potential for introgression following hybridization.

For the purposes of this report this particular aspect has been considered separately as it is recognised as a particularly relevant problem for the aquaculture sector.

Exotic species might be used in all forms of aquaculture, although their release into the wild is likely to occur more from open and semi-open systems such as lagoon and cage culture. Land-based systems tend to have greater containment integrity although stock losses into the wild are always possible.

In terms of current European legislation governing the introduction of alien species, the Habitats Directive requires Member States to "ensure that the deliberate introduction into the wild of any species which is not native to their territory is regulated so as not to prejudice natural habitats within their natural range or the wild native fauna and flora and, if they consider it necessary, prohibit such introduction". However, it is unclear how both the accidental, non-deliberate introductions and the introductions into non-wild environments are covered by this legislation. The EC is currently considering introducing a regulation to permit the use of alien or 'locally-absent' species in aquaculture through a framework that includes (i) procedures for the analysis of the potential risks, (ii) the taking of measures based on the prevention and precautionary principles and (iii) the adoption of contingency plans where necessary (EC, 2006).

5.11.2 Determination of Evaluation Variables

As mentioned previously, long-term impacts from the introduction of alien species include habitat alterations, trophic alterations, spatial alterations (i.e. displacement) and introduction of parasites and diseases or interbreeding which have been already been treated separately in more detail.

No linear relationship can be established between these potential impacts the introduction of one alien species because of the variety of environmental variables involved. Therefore, many areas of uncertainty still remain in the use of introduced and newly domesticated species (Bartley 1999).

Unfortunately, a robust theory of invasion biology is not yet available (Townsend 1991). A theory which incorporates an understanding of likely ecological impacts would permit rational decisions about which species are safe to import and which accidental introductions should take priority in eradication efforts. A basic problem is that there are generally far too few data to demonstrate how introduced species affect native species.

It is axiomatic that the more diverse the autochthonous fish community and the more complex the limnological ecosystem into which an alien species is introduced, the less will be its immediate significance. The most successful naturalized fishes are usually established where indigenous fish communities are either comparatively fragile or are composed of relatively few species, or which are already under the influence of overfishing or environmental disturbance. Therefore, although the effects of introductions are hard to predict, exotic fishes are most likely to become naturalized:

- in a mild climate,
- in disturbed or man-made habitats such as reservoirs and canals, and
- in communities with a low species diversity.

The effects of introductions of aquatic organisms on the environment are frequently surprising especially as the new species may adopt a niche that differs completely from the occupied in its native range.

Apart from disease related effects which may be independent, serious impacts on the environment can be anticipated from two main classes of species: those whose reproductive pattern enables them to form stunted populations, and major predators, especially where these are introduced into communities which lack ichthyophages (EC 2001).

The ICES Code of Practice on the Introductions and Transfers of Marine Organisms (2004a) defines a methodology to assess the risk that an introduced species poses to the hosting environment and native species. ICES risk assessment framework illustrates clearly the number of variables involved in determining the potential impact of an introduced species and shows the complexity of undertaking such an assessment. The success of an invasive species is largely determined by fluctuating biotic and abiotic conditions that determine the window of opportunity for establishment.

Table 26: ICES Invasive Species Risk Assessment Framework

Assessment parameter	Risk estimate *	Uncertainty estimate *
Estimate of probability of the organism successfully colonizing and maintaining a population in the intended area of introduction		
Adequate food resources		
Habitat suitability		
Biotic resistance		
Abiotic resistance		
Can reproduce		
If organism escapes from the area of introduction, estimate the probability of its spreading		
Ability for dispersion		
Estimated range of probable spread		
Human intervention to retard, enhance spread		
Likely areas of further colonization		
Ecological magnitude on native ecosystems both locally and within the drainage basin		
Predation effects on native species		
Prey availability		
Habitat availability		
Does NIS (non-indigenous species) enter or alter native habitats		
Does NIS affect quantitatively or qualitatively the availability of food for native sp.		
Does NIS prey on species of concern		
Genetic impacts on self-sustaining stocks or populations		
Does NIS encounter or enter species of concern		
Does NIS affect the survival of local species		
Does NIS affect the reproduction of local species		
Does NIS affect the genetic characteristics of local stocks		
Probability of establishment estimate of a pathogen or parasite		
Estimate probability that a pathogen or parasite may be introduced and may encounter susceptible organisms or suitable habitats		
Ecological impacts on native ecosystem		
Impacts within drainage basin		
Disease outbreak		
Reproductive capacity reduction		
Habitat changes		
Mitigation factors (Note: Risk is lowered if the following are achieved)		
Health inspection certification		
Pre-treatment for parasites, diseases, and parasites		
Inspection for fellow travellers		
Disinfection prior to discarding water in which organisms arrived		
Vaccination		
Disinfection of eggs		
Importation as milt or fertilized eggs only		
Use of quarantine for incoming organisms, (used as broodstock). Release F1 progeny only, provided no pathogens, parasites, or fellow travellers appear		

* Based on the information provided by the proponent of the request, the risk assessor(s) can rank the **risk estimate** as: 3 = high probability; 2 = medium probability; 1 = low probability; ND = no data. In addition the quality of the available data is assessed as **uncertainty estimate**: 4 = very certain; 3 = reasonably certain; 2 = reasonably uncertain; 1 = very uncertain; ND = no data

Evaluating the level of habitat, trophic or spatial alteration, for a given introduction requires continuous and focused monitoring of all the variables mentioned which is often costly and not practical. resulting in lack of sufficient and reliable data.

There seems to be two possible solution to this problem:

1. Use of environmental indicators as proxies for a particular situation (e.g. reduction in extension of seagrass beds), provided the value of these indicators is regularly monitored. Clearly, different indicators will have to be used depending on the type of ecosystem or geographical area (e.g. Mediterranean as opposed to the Atlantic) making comparison from one area to the other very difficult.
2. As, ultimately, all the mention impacts result in the reduction in population size of autochthonous (i.e. native) species, the risk of extinction to which these populations are exposed as a consequence of the introduction of an allochthonous (i.e. alien) species can be used as an effective classification element. Given the IUCN has developed internationally recognised classification criteria for threatened species, this approach is probably more effective and practical.

Magnitude: could be evaluated on the basis of two simple and intuitive criteria :

a. the number of individuals of exotic species escaped from the farm (or released)
b. the degree of physical occupation of the ecosystem by the alien species

The second criteria has been suggested as an indicator of the degree of influence (low to high) of non-native species in major U.S. estuaries (HCSEE 2002). The table below shows the proposed framework for evaluating the magnitude of alien species pressure on an ecosystem. Both the number of alien species and the area they inhabit (or their biomass) are factors, so this measure proposes a combined ranking approach, in which both factors contribute to an overall score. The values presented in the table are arbitrary and are intended only to illustrate the utility of such a ranking system.

Table 27: Proposed Framework for Evaluating Magnitude of Alien Species Pressure

% of area inhabited or % of total biomass of alien species	% of Alien species / Total species		
	<25	25–75	75–100
<25	1 (low)	2 (low)	3 (medium)
25–75	2 (low)	3 (medium)	4 (high)
75–100	3 (medium)	4 (high)	5 (high)

Source : HCSEE 2002

Significance: As mentioned, there is no linear relationship between the number of individuals escaped or the space occupied (magnitude) and the significance of the effects on the receiving ecosystems. The most obvious and significant of these effects is, ultimately, the reduction in the population of one or more of the native species or, in other words, the risk of extinction to which these species are exposed as a consequence of the introduction of the alien species. Following IUCN Red List threatened species categories (IUCN 1994), the first classification criteria is an observed, estimated, inferred or suspected reduction of the population over the last 10 years or three generations, whichever is the longer, based on any of the following :

a) direct observation
b) an index of abundance appropriate for the taxon
c) a decline in area of occupancy, extent of occurrence and/or quality of habitat
d) actual or potential levels of exploitation

Duration: the frequency of alien species escapes is intuitively another important element determining the potential impact to which native species and receiving ecosystems are exposed. The probability of invasion success increases with repeated introduction and is frequently preceded by numerous failures (Naylor *et al.* 2005). Apparently, no study has defined a clear relationship between the frequency of escapes or releases in the environment and the probability of a species to become a successful coloniser of a new ecosystem. Nevertheless, it could be argued that, in theory, only one escape or release could be a sufficient basis for the successful reproduction ad spreading of an alien species in the environment (particularly for those species which have asexual reproduction and are able to disperse rapidly).

Distribution: The distribution of an alien species is primarily a function of the time elapsed since its introduction and its success in colonising the receiving ecosystem. The variables determining the colonisation success of an alien species have been well outlined in the ICES Risk Assessment Framework provided above. On this basis, a series of combinations implying different levels of potential pressure can be envisaged :

1. *recent introduction of a poor coloniser* : the alien species is unlikely to pose any threat to the receiving ecosystem and/or native species in the long-term and distribute into a wide area. Nevertheless, the situation has to be monitored closely as the species might reveal more adaptable then expected on the basis of its known biological characteristics.
2. *past introduction of a poor coloniser* : the permanence of the alien species in the wild is maintained only by frequent escapes or releases but the species has proved unable to adapt to the receiving ecosystem and will not be able to distribute over a wide area.
3. *recent introduction of a successful coloniser* : the species poses a serious threat to the receiving ecosystem and/or native species in the long-term and it is likely to distribute widely depending on the characteristics of its life cycle (e.g. planktonic larval stage as oppose to demersal larval stage, sexual reproduction as opposed to sexual reproduction) and the characteristics of the receiving ecosystem (e.g. enclosed sea as opposed to the ocean)
4. *past introduction of a successful coloniser* : the species is likely to be already widely distributed depending on the parameters mentioned above (life cycle and receiving ecosystem characteristics).

Clearly, this categories represent the extremes of a spectrum of intermediate possibilities influencing the distribution range of an introduced alien species. Nevertheless, this operational classification is useful for management purposes as it is not based exclusively on spatial parameters but accounts for biological parameters, environmental conditions and time of introduction.

5.12 INDIRECT ECOSYSTEM PRESSURES

5.12.1 Characterisation of Pressure

In the context of the present report, we refer to indirect ecosystem pressures deriving from aquaculture as those pressures occurring *upstream* of the aquaculture activity as such, therefore :

- Pressure is exerted in areas which are not necessarily those in which the aquaculture farm is located
- Pressure does not fall directly under the control of the farm owners or managers

The main pressures of this type are associated with aquaculture activities which :

1. require the harvest of individuals in the wild to supply aquaculture farms with juveniles (capture-based aquaculture)
2. require feed of animal (fish) origin to grow aquaculture species

Capture-based Aquaculture

Capture-based aquaculture is, in practice, an overlap between aquaculture and fisheries since it is based on the removal of "seed" from the wild stocks for subsequent on-growing in captivity using traditional aquaculture techniques.

The impacts deriving from wild seed harvesting may be classified as direct or indirect. Direct impacts include :

- Over-fishing of targeted source populations
- Removal of immature fish from the genetic stock (recruitment success)
- By-catch or discards of non-target species caught along with the targeted seed
- Physical impacts on benthic habitats and species by the use of detrimental fishing methods

Indirect impacts include mainly the effects on the marine ecosystems structure and function caused by fishing activities.

These impacts will be briefly analysed below on the basis of a recent FAO publication on capture-based aquaculture (FAO 2004).

<u>Overfishing</u>: most species used in capture-based aquaculture (e.g. tuna, groupers) are species with a high commercial value and are, therefore, already heavily exploited by commercial fisheries. In addition these same species present biological characterised which tend to make them more vulnerable (i.e. late reproduction, long life, formation of spawning aggregations).

Capture-based aquaculture seems to influence the status of some grouper populations in SE Asia due to the harvesting of wild seed (Sadovy 2000). In the South Mediterranean Sea over-exploitation of juvenile classes of amberjack (*S. dumerili*) has been signalled since the early 90s (Andaloro 1993, Mazzola et. al. 1993). The limited availability of amberjack juveniles currently represents a bottleneck for capture-based aquaculture in the Mediterranean.

The state of most tuna stocks is also considered at risk but, in general, today it is difficult to evaluate the stocks due to lack of scientific information.

Globally, the catch of wild eels of all species has decreased continuously for 25 years (Tanaka 2001) and the shortage of "seed" has become a constraint for capture-based aquaculture.

<u>Recruitment success</u>: all species used for capture-based aquaculture have external fertilisation (spawning of gametes) and a planktonic larval stage of variable duration before the larvae settles and turns into a young adult (recruit). Natural mortality rates of larvae and recruits is very high in pelagic spawning fishes (Sadovy and Pet 1998) but the exact causes of this mortality are still unknown.

Most of the mortality seems to be concentrated at the larval stage and drops considerable after settlement of recruits. Given harvesting for aquaculture purposes occurs after settlement and the seed may be up to one year old at capture, the fishing mortality of young recruits may represent a substantial portion of total mortality from spawning to adulthood. If this is the case, harvesting of seed should be appropriately managed to avoid over-fishing.

<u>Bycatch</u>: the level of bycatch associated with the collection of wild seed for aquaculture is not well documented. The same fishing gear could cause different bycatch impacts depending on the area in which it is used. For example, purse seine fishing for bluefin tuna for aquaculture in the Mediterranean is very efficient and does not entail bycatch but this is not so in other areas (e.g. bycatch of cetaceans in the Pacific).

Often the seed for aquaculture is collected using Fish Aggregating Devices (FADs) or natural structures (e.g. underwater mountains etc.). Amberjack (*S. dumerili*) in the Mediterranean are known to associate with FADs. Harvesting fish associated with natural or artificial FADs may result in an increased catch and excessive mortality rates for juveniles or pre-reproductive individuals of non-target species (Hall 1998).

The use of trawls for eel fishing, due to the small mesh size, effects many juvenile fish and up to 90% of the catch consists of non-target species (Hahlbeck 1994).

Aquaculture feeds production

The intensive production of mainly carnivorous species in Europe requires a high demand for fishmeal and fish oil in their diets. With typical grow-out diets containing between 30-50% protein and 10-25% oil, European aquaculture currently consumes around 615,000 tonnes fishmeal per year, thus requiring around 1.9 million tonnes of feed fish[18]. The main sources of these feedfish are the small pelagic stocks of Northern Europe, as well as the Peruvian anchovy and Jack mackerel of South America. In addition, around a third of fishmeal is produced from trimmings and the bycatch of food fisheries. The utilisation of fishmeal for aquaculture is likely to fall on a per unit basis as inclusion rates drop through the use of alternative vegetable-based substitutes as well as greater efficiencies in feeding and nutrition. With the conservative rise of European aquaculture production of 2% per annum, fishmeal use is likely to rise to 629,000 tonnes and fish oil to 343,000 tonnes by 2015.

The feed fisheries have a low economic contribution to the fisheries sector as a whole, providing an estimated 0.5% of the EU's fisheries-related employment and 2.1% of the sector's value added. Nearly half (45%) this employment is in the catching sector with the rest in feed fish processing (19%) and fish trimming (35%). The adoption of technically advanced catching and processing methods have ensured that feed fisheries-related employment remains low. However this low level of dependency hides localised relatively high levels in the fleets of Denmark and Sweden, where feed fisheries are interwoven into a substantive part of the fisheries sector as a whole.

The main impacts of this demand are upon the feed fish stocks as well as linked elements of the food chain. Feed fish are mainly bony small pelagic fish with short lives and a high level of inter-annual variability that may depend upon extrinsic, often climate-related factors. As such they are difficult to manage on a multi-annual basis when compared to longer-lived stocks where the state of successive year classes entering the fishery can be monitored in advance. Fortunately the high levels of fecundity allow stocks to recover relatively quickly and thus they are protected to a certain degree from high levels of exploitation. What is less certain is the consequences of stock variability on natural predators such as gadoids, marine mammals and seabirds as well as the contribution of fishing mortality to these effects. Recent work suggests that so long as fishing mortality remains below natal mortality, feed fisheries may not cause problems for their predators on the scale of the stock. However locally concentrated harvesting may cause local and temporary depletions, which might affect sub-populations of species like sand eel and their natural predators at a local level.

As can be inferred from the above, judging the sustainability of feed fish stocks is complex. Although quality and price are the main determinants for fishmeal purchasers in the aquafeeds industry, the sustainability of feed fish sources is beginning to become more important. At present, most buyers depend upon the FIN 'Sustainability Dossier' for information on what stocks are 'sustainable' or not, but there is a recognised need for a comprehensive analytical framework that integrates target stock assessment with the wider ecosystem linkages. To a

[18] Assuming 66% fishmeal is derived from feed fisheries and that it takes 4.8 tonnes of feedfish to produce one tonne of fishmeal

degree this exists with the development of ecosystem models and approaches such as the MSC criteria for 'responsible fishing'. Once such a framework has been created and is accepted as a suitable benchmark by the aquafeed industry and their detractors, then it will be easier for purchasers to purchase only from sustainable feed fish stocks. This process will inevitably have consequences, such as greater pressure on those stocks deemed as sustainable as well as possible effects on market economics. This implies that greater use of vegetable-based substitutes will be essential, which in turn may require a reduction in consumer attitudes towards their inclusion in farmed fish diets.

The number of feed fisheries targeted for fishmeal in Europe have little alternative uses. However some, like blue whiting, capelin, anchovy, herring and sprat can be used for direct human consumption. The proportion that goes for human consumption depends largely on economic and cultural factors rather than technical limitations, which are more difficult to address directly by the industry. Furthermore, recent work by ICES (ICES, 2004c) questions the immediate assumption that the reduction of fish into fishmeal and subsequent use in aquaculture is less efficient that leaving the fish in the sea to supply predators further up the food chain. It then goes on to state that so long as the food conversion efficiencies are regularly reviewed, then a closely regulated combination of industrial and human consumption fisheries may provide the only solution to the long-term demand for fish protein.

Determination of Evaluation Variables

The elements effecting the indirect ecosystem effects of aquaculture are directly related to the portion of capture fisheries which can be directly attributed to seed harvesting or feeds production.

Many marine fish stocks are currently subject to ineffective management measures. This is true not only for little known resources or for difficult to assess highly migratory species of the high seas, but also to well-studied demersal resources of northern continental shelves where recent dramatic stock declines have been registered for some important species (FAO 1994).

In European waters the state of many commercial stocks has not yet been assessed, ranging from approximately 20% on average in the North-East Atlantic to 80% in the Mediterranean Sea. In general, amongst the European assessed stocks between 10 and 50%, depending on the geographical area, are considered to be outside safe biological limits (SBL) or overfished.

Capture fisheries management is based on the well known and studied variables, indicators and reference limits summarised in the table overleaf.

The many technical reference points which have been proposed for rational exploitation of fishery resources can, in terms of their use, be placed in two categories : Target Reference Points (TRPs) and Limit Reference Points (LRPs).

Target Reference Points have been considered as indicators of a stock status which is a desirable target for management. It has been assumed that managing a fishery corresponds to adjusting the inputs to (i.e. capacity), or outputs from (i.e. effort), a fishery until one or more of variables correspond to the TRP chosen. MSY has most often been used in this sense. TRP management requires active monitoring and continual readjustment of management measures on an appropriate (usually annual) time-scale. It also requires attention to the effect of a variety of sources of uncertainty on the estimates of the TRP and of stock status (Caddy & Mahon 1995).

In order to protect the resource and the fishing industry against long-term damage, it is important to define and agree on a 'red area' where the continuity of resource production is in danger, and immediate action is needed, such as a substantial reduction in fishing effort/mortality, or in the extreme case, closure of the fishery for a period of time (ICES 1988). Reference points which indicate when such a danger area is about to be entered can be referred to as Limit Reference Points (LRPs). An LRP may either correspond to some minimum condition (e.g. a dangerously low spawning biomass) or some maximum condition (a high rate of decline in stock size, or a high mortality rate) at which point a management response is automatically triggered (Caddy and Mahon 1995).

Table 28: Indicators and reference points generally used in fisheries management

Indicators	Potential reference points	Potential ratios
Yield (Y)	Maximum Sustainable Yield (MSY) Maximum Constant Yield (MCY) Maximum Economic Yield (MCY) Long-term Average Yield (LTAY)	Ratio of current effort to that at MSY (f/f_{MSY})
Fishing Mortality (F)	F at MSY (F_{MSY}) F at MCY (F_{MCY}) F at MEY (F_{MEY}) F at LTAY (F_{LTAY}) F at which the slope of the Y/R curve equals 10% of the slope near the origin ($F_{0.1}$) F at the level of maximum yield per recruit (F_{MAX}) F at recruitment failure (F_{crash})	Ratio of current fishing mortality rate to that at MSY (F/F_{MSY})
Biomass (B) & Spawning Stock Biomass (SSB)	B when the stock is fished at F_{MSY} (B_{MSY}) B when the stock is fished at F_{MCY} (B_{MCY}) B corresponding to 30% of the virgin biomass at F=0 ($0.3B_V$) SSB at which R (recruitment) = 50% R_{max} ($B_{50\%R}$) SSB at which R (recruitment) = 90% R_{max} ($B_{90\%R}$)	Ratio of current stock biomass or spawning biomass to that at MSY (B/B_{MSY}) Ratio of current stock biomass or spawning biomass to virgin biomass (B/B_V)

Source : adapted from FAO 1999

Magnitude : can be referred to the fish catch or landings measured in metric tonnes by species, area, no. of vessels or time (i.e. catch per unit effort or CPUE) for species directly related to the production of feeds for aquaculture and for harvesting of wild seed. As mentioned, this portion (particularly for feeds) appears to be consistent and on the increase (FAO 1998).

Significance : the effort itself or the landings in general do not provide sufficient indication on the significance of the pressure exerted on wild stocks, which depend on the rate of exploitation, on the biological characteristics of the stock and on other unpredictable environmental variables which influence the ability of new recruits to join the existing population successfully and reach maturity. Fishing mortality (F) and other variables such as MSY and Biomass (B) are generally used to determine the level of exploitation of a stock. Evaluating the portion of F directly related to aquaculture activities (i.e. seed harvesting and feeds) would be a good indication of the risk of aquaculture actually contributing to the exploitation of a stock. Clearly, any fishing pressure on stocks classified as overexploited or depleted would be very significant, while an heavy pressure on a fully exploited or underexploited stock would not be considered as such.

Duration : pressure duration depends on the extension of the fishing period for each particular species. Fishing mortality (F) can be controlled by restricting fishing activities to particular times or seasons.

Distribution : depends on the fishing range of each particular species. In general, the smaller extent of occurrence and area of occupancy (as defined by IUCN) of a species targeted by fisheries activities, the higher will be the risk of overexploiting it. Nevertheless, due to dramatic improvements in fishing and communications technology, fishing pressure can be exerted ever more rapidly and moved from one fishery to another within short time periods. In addition, some fish species create spawning aggregations at particular times of the year which make them very vulnerable to mass harvesting of sexually mature adults. As for duration, fishing mortality (F) can be controlled by restricting fishing activities to particular areas.

6 HABITAT AND SPECIES DESCRIPTION, ECOSYSTEM IMPORTANCE AND SENSITIVITY

The purpose of this section is to present a summary of the general sensitivity of key habitats identified in Section 2.2 to principal pressures associated with aquaculture activities (see Section 5). As such, this section presents a basis upon which risks can be determined.

A large amount of work has been carried out by other projects reviewing the sensitivity of habitats to environmental change, particularly, the Marine Habitats Review for the Irish Sea Pilot Project, 2000; the Marine Life Information Network for Britain and Ireland (MarLIN); and the UK Marine SACs Project, 1996 – 2001. Outputs from these projects provide the key sources of information for the information presented below.

'Sensitivity' is dependent on the intolerance of a species or habitat to damage from an external factor and the time taken for its subsequent recovery. The assessment below is therefore concerned with describing the intolerance and recoverability of a habitat/species to principal pressures.

The sensitivity of habitats discussed is dependent upon the species present and is likely to vary between individual biotopes. In addition, sensitivity will be dependent upon site-specific local background conditions and the degree of change related to these (i.e. exposure). It is not possible to provide a site-specific and comprehensive biotope assessment here. A generalised approach has therefore been taken forward based on key functional species within each habitat type discussed. Key species are discussed separately.

The table overleaf provides a summary of the sensitivity analysis presented below.

6.1 REEFS

Reefs are listed in Annex I of the Habitats Directive. The most important reef building species are mussel bed communities comprised of *Mytilus edulis and Modiolus modiolus* and polychaete worm reefs comprised of *Sabellaria alveolata* and *S. spinulosa*. In this section reefs are broken down to a discussion of (i) mussel bed communities and (ii) polychaete worm reefs as their sensitivities are different.

A. Mussel Bed Communities

6.1.1 Background

Habitat description: mussel bed communities can exist on rocky shores and sublittoral sediments. *Mytilus edulis* occurs from the high intertidal to the shallow subtidal zones attached by fibrous byssus threads to suitable substrata. Found on the rocky shores of open coasts attached to the rock surface and in crevices, and on rocks and piers in sheltered harbours and estuaries, often occurring as dense masses. *Modiolus modiolus* communities are found part buried in soft sediments or coarse grounds or attached to hard substrata, forming clumps or extensive beds or reefs. May be found on the lower shore /sah/glossary.php?term=lower shore in rock pools or in laminarian holdfasts but more common sub-tidally.

Ecosystem Importance: Mussels contribute to the zooplankton (larva), which forms an important food source for other species. Dense beds increase turnover of nutrients and organic carbon in estuarine environments through pelagic-benthic coupling. Mussels are important food sources for wildfowl, including oystercatchers and eider ducks. In addition, a reduction in mussel availability can lead to increased predator pressure on other species such as cockles *Macoma balthica* (Holt *et al.*, 1998). A wide variety of other organisms have been found to be important predators on mussels and include limpets, predatory gastropods, crabs, lobsters, urchins, fish, otters and seals.

Table 29: Sensitivity of Key Habitats and Species to Aquaculture Pressures

Habitat / Species	Pressure Categories													
	1. Smothering		2. Change in bio-geochemistry		3. Change in coastal processes	4. Infrastructure impacts	5. Visual land & seascape modification	6. Disturbance	7. Predator Control	8. Chemical Use	9. Pathogen Transmission	10. Inter-breeding with wild organisms	11. Introduction of alien species	12. Indirect ecosystem pressures
	Smothering	*Turbidity*	*Dissolved 0_2*	*Nutrients*										
Reefs: Mussel Bed Communities	High	Low	Moderate	Moderate	Moderate	High				High	Moderate			
Reefs: Polychaete Worm Communities	High	Low	High	?	Low	High				?	?			
Seagrass Beds on Sublittoral Sediments	High	Moderate	High	High		High			Low	High			High	
Sandbanks, Mudflats & Sandflats	High	Moderate	High	High	Low	High	High	High	Low	High			Low	
Maerl Beds	High	Moderate	High	High	Moderate	High				?			High	
Kelp and Seaweed Communities	High	High	High	High		Moderate	Low			?			High	
Saltmarsh Communities	Low		Low	Low	Low	Moderate	Moderate	Moderate	Low	High	?			
Sand Dune Communities					Moderate	Moderate	Moderate	Moderate	Moderate	Low				
Shingle Communities	Low					Moderate	Moderate	Moderate	Low		?			
Cetaceans								Moderate	High	Moderate				
Pinnipeds								Moderate	Low	Moderate				
Otters	Low					Low		Low	Low	Low				
Fish	Low		Low					Low		Low	High	High	Low	High
Birds	High	Moderate	High			High		Low	Low	Moderate				High

Sensitivity Key

High	Moderate	Low	Negligible	? Uncertain

6.1.2 Sensitivity Assessment

Sedimentation*:* Mussels may suffer from the impacts of sedimentation in two ways – the physical smothering of individuals due to the effects of increased turbidity and increased material in suspension. These two impacts are addressed separately with respect to tolerance, recoverability and sensitivity.

Mussels are able to move within a bed or to resurface when buried by sediment (Holt *et al.*, 1998). However, it is expected that a proportion will succumb to the effects of sedimentation. Mussel communities have been reported to suffer mortalities as a result of smothering by large-scale movements of sand or sand scour (Daly & Mathieson, 1977; Holt *et al.*, 1998). Similarly, bio-deposition within a mussel bed results in suffocation or starvation of individuals that cannot re-surface. Increased deposition may fill the mussel matrix, resulting in increased abundance of infauna but loss of more mobile species and species richness (Tsuchiya & Nishihira, 1985, 1986). The space for mussel spat and other small invertebrates to shelter between mussels will be reduced. Tolerance is considered intermediate. Recoverability may occur with a good annual recruitment. However, continual bio-deposition may mean that recoverability is low. Sensitivity is therefore high.

Mussels may benefit from increased material being in suspension, especially in the form of organic particulates and dissolved organic matter. Sensitivity is, however, low.

Change in bio-geochemistry: mussels are regarded as generally tolerant of a wide range of oxygen concentrations including zero (Zwaan de & Mathieu, 1992). Diaz & Rosenberg (1995) suggest that mussels are resistant to severe hypoxia. Although mussels are highly tolerant of hypoxia, it incurs a metabolic cost and therefore could reduce growth. Jorgensen (1980) observed the response of macrofauna to reduced dissolved oxygen (DO) levels of 0.2 to 1 mg l^{-1} for a period of 3 to 4 weeks in an estuarine/marine area in Sweden by diving. Mussels (*Mytilus edulis*) were observed to first close their shells and survived for 1 to 2 weeks before dying. Once oxygen levels return to prior levels, mussels will probably recover condition within a few weeks. Tolerance is intermediate and recoverability in the short term high. Sensitivity is therefore moderate.

Mussels may benefit from moderate nutrient enrichment, especially in the form of organic particulates and dissolved organic matter. The resultant increased food availability may increase growth rates and reproductive potential. However, filter feeders are likely to accumulate toxins from toxic algae which may be associated with areas of nutrient enrichment and algal blooms. The accumulation of such toxins in mussels has resulted in the closure of shellfish beds (Shumway, 1992). An increase in ephemeral algae may increase smothering of mussels and increase drag, which will render the mussels more susceptible to dislodgement under increased water flow in exposed areas (i.e. during storms). Intolerance is intermediate and recoverability intermediate. Sensitivity is therefore moderate.

Change in coastal processes: reduced water flow rates could lead to a decrease in the supply of food (suspended particulates, benthic diatoms and phytoplankton). The range of water flow rates in which mussels inhabit would, however, suggest that mussels are tolerant to a change in water flow rate. The ability for recoverability is dependent upon the length of time in which food supply is reduced. Once the prior water flow regime returns, the population will probably recover within a few months. However, if this is a long term problem recoverability will be low. Tolerance is therefore considered to be intermediate and recoverability intermediate. Sensitivity is therefore moderate.

A reduction in water flow could also increase sedimentation and smothering. These issues have been discussed separately in the previous section on sedimentation.

Infrastructure impacts: The loss of substratum will lead to the loss of the entire population within the footprint. Physical disturbance could remove species within mussel bed communities. A single good recruitment event may re-colonise the substratum within a year, recovery of the whole community may take years. Tolerance is therefore considered low and recoverability low. Sensitivity is therefore high.

Visual land and seascape modification: mussel bed communities are unlikely to be sensitive to visual disturbance. It is considered that there is no sensitivity with respect to this pressure.

Disturbance: mussels and associated invertebrate species are likely to be insensitive to noise disturbance. However, birds are major predators of mussels and several bird species are intolerant of noise. Therefore, noise may disturb predatory birds, so that the mussel populations may benefit indirectly. There is therefore no sensitivity with respect to this pressure.

Predator control: any structures and/or netting placed beneath the water surface as part of an anti-predator device provide opportunity for colonisation by mussels. Mussel bed communities are, however, generally insensitive to predator control techniques. Any control measures that lead to the disturbance of predators (e.g. birds) may be of direct benefit to mussel communities. Overall, it is considered that there is no sensitivity with respect to this pressure.

Chemical use: suspension feeders process large volumes of water together with suspended particulates and phytoplankton. Mussels absorb contaminants directly from the water, through their diet and via suspended particulate matter. A recent study carried out by the Scottish Association for Marine Science (SAMS, 2005) has, however, determined that there was little effect on sublittoral mussel bed communities in Sea Lochs in Scotland associated with sea lice treatment. Barnacle reproduction on rocky shores was, however, seen to be affected and further investigation has been recommended by the SAMS report. However, the test sites are located in a highly regulated environment and it is expected that the use of chemicals at higher levels could have significant effects. In addition, to sea lice treatments other contaminants include metals from antifoulants and fish feed and antimicrobial compounds in fish feed could be present. Given the ability of mussels to accumulate contaminants and the potential for toxicity, it is considered that tolerance at unregulated levels would be low and recoverability low. Sensitivity is therefore high.

Pathogen transmission: mussels host a wide variety of disease organisms and parasites from many animal and plant groups including bacteria, blue green algae, protozoa, boring sponges, boring polychaetes, boring lichen, the intermediary life stages of several trematodes, the copepod *Mytilicola intestinalis* (red worm disease) and decapods e.g. the pea crab *Pinnotheres pisum* (Bower, 1992; Bower & McGladdery, 1996). Significant infestations may result in loss of a proportion of the mussel population, either through mortality or reproductive failure. Tolerance is intermediate and recoverability intermediate. Sensitivity is therefore moderate.

Inter-breeding with wild organisms: Not relevant.

Introduction of alien species: Not relevant.

Indirect ecosystem impacts: Not relevant.

B. Polychaete Worm Reefs

6.1.3 Background

Habitat description: sublittoral reefs of polychaete worms in mixed sediments are found in a variety of hydrographic conditions. Such habitats may range from extensive structures of considerable size to loose agglomerations of tubes. Tide-swept sandy mixed sediments with cobbles and pebbles, in variable salinity or fully marine conditions, may be characterised by surface accumulations of the reef building polychaete *Sabellaria alveolata or S. spinulosa*. Other associated species may include the polychaete *Melinna cristata*, itself often as dense aggregations, mobile surface feeding polychaetes including *Typosyllis armillary* and *Eulalia tripunctata*. Other polychaetes may include *Mediomastus fragilis* and *Pygospio elegans* whilst amphipods such as *Harpinia pectinata* and tubificid oligochaetes may also be found.

Ecological importance: there is little detailed mention in the literature of predation on *S. alveolata*, although *Carcinus maenas* was a troublesome predator of transplanted portions of reefs in Somerset (Bamber & Irving 1997). Herdman (1919) mentioned that flatfish such as plaice *Pleuronectes platessa* and sole *Solea solea* could easily obtain the worms by crunching up the brittle sand tubes. Worms are known to be able retract considerable distances down their tubes (Cunningham *et al.* 1994; Wilson 1971); it would therefore appear to be difficult for predators to extract worms easily from compact reef masses.

6.1.4 Sensitivity Assessment

Sedimentation: *Sabellaria* sp. are tolerant to burial under sediment for up to several weeks. Recoverability is almost immediate (Wilson, 1971). Long term burial by sand has, however, been shown to kill *S. alveolata* reefs (Perkins 1967). Tolerance is low and recoverability intermediate. Sensitivity is therefore high.

Sabellaria sp. may benefit from increased material being in suspension, especially in the form of organic particulates and dissolved organic matter. Sensitivity is, however, low.

Change in bio-geochemistry: *Sabellaria alveolata* has intermediate intolerance to decreases in oxygenation. Cole *et al.* (1999) suggest possible adverse effects on marine species below 4 mg/l and probable adverse effects below 2mg/l. Tolerance is intermediate and recoverability low. Sensitivity is therefore high.

Insufficient information is available to determine sensitivity with respect to nutrient enrichment.

Change in coastal processes: a reduction in water flow that reduces the availability of suspended particles may hinder growth and repair and feeding. The ability for recoverability is dependent upon the length of time in which supply is reduced. If this is a long term problem recoverability will be low. Tolerance is considered to be intermediate and recoverability intermediate. Sensitivity is therefore moderate.

A reduction in water flow could also increase sedimentation and smothering. These issues have been discussed separately in the previous section on sedimentation.

Infrastructure impacts: the loss of substratum will lead to the loss of the entire population within the footprint. Tolerance is low and recoverability intermediate. Sensitivity is therefore high.

Physical disturbance is known to be one of the biggest issues for polychaete worm reefs. Tolerance is low and recoverability intermediate. Sensitivity is therefore high.

Visual land & seascape modification: not relevant.

Disturbance: not relevant.

Predator control: not relevant.

Chemical use: insufficient information is available to determine sensitivity.

Pathogen Transmission: insufficient information is available to determine sensitivity.

Inter-breeding with wild organisms: not relevant.

Introduction of alien species: not relevant.

Indirect ecosystem impacts: not relevant.

6.2 SEAGRASS BEDS ON SUBLITTORAL SEDIMENTS

The main seagrass species have been discussed below as impacts are similar. However, of note, *Posidonia oceanica* communities are listed under Annex I of the Habitats Directive and therefore this species is of key European importance.

6.2.1 Background

Habitat Description: there are four European species of seagrass:

- *Posidonia oceanica;*
- *Zostera marina* (eelgrass);
- *Zostera noltii* (dwarf eelgrass);
- *Cymodocea nodosa.*

Posidonia oceanica is restricted to the Mediterranean Sea and its distribution stops at the boarder line where Mediterranean and Atlantic waters mix in the western part of the Mediterranean Sea. *P. oceanica* grows from shallow subtidal waters to 50-60m depth in areas with very clear waters.

Zostera marina is found from arctic waters along the northern Norwegian coast, where it can survive several months of ice cover, to the Mediterranean. The species is very abundant in the Baltic Sea, the North Sea and along the Atlantic coasts down to northern Spain. Further south, *Z. marina* becomes rarer and in the Mediterranean the species is mostly found as small isolated stands, but dense eelgrass beds do occur, especially, in lagoons. *Z. marina* is predominantly subtidal and may exist down to 10-15m depth depending on water clarity.

Zostera noltii (dwarf eelgrass) is distributed from the southern coasts of Norway to the Mediterranean Sea, the Black Sea, the Canary Islands and has been recorded as far south as on the Mauritanian coast. *Z. noltii* forms dense beds in the muddy sand of intertidal areas, where *Zostera marina* is sparse due to its lower tolerance to desiccation

Cymodocea nodosa is a warm water species and is widely distributed throughout the Mediterranean, around the Canary Islands and down the North African coast. The species does not extend further north than the southern coasts of Portugal. *C. nodosa* can be found from shallow subtidal areas to very deep waters (50-60m).

Ecological Importance: living seagrass leaves provide a suitable substratum for numerous epiphytic algae, while other algae live between the seagrass shoots and within the surface layers of the underlying sediment. The algae found within seagrass beds are more digestible than the seagrass itself and support the majority of the abundant grazers found within seagrass communities.

A wide variety of invertebrate species occur on and among the plants of a seagrass bed. Small gastropods grazing the algal epiphytes on the leaves include *Hydrobia* sp., *Rissoa membranacea* and *Littorina littorea*. The sediments underlying the beds support large numbers of polychaete worms (e.g. *Arenicola marina* and *Lanice conchilega*), bivalve molluscs (e.g. *Cerastoderma edule* and *C. glaucum*) and burrowing anemones (e.g. *Cereus pedunculatus*). Amphipod and mysid crustaceans are among the most abundant and important of the mobile fauna living amongst the leaves. Seagrass beds are also important spawning and nursery areas for many species of fish, including commercial species. Wildfowl (ducks and geese) are among the few animals, which graze directly upon seagrass and are able to digest its leaves, including wigeon and Brent geese.

6.2.2 Sensitivity Assessment

Sedimentation: Seagrass is intolerant to smothering. It will typically bend over with the addition of sediment and can become buried in a few centimetres of sediment (Fonseca, 1992). Tolerance is intermediate and recoverability low. Sensitivity is therefore high.

Increased turbidity associated with increased organic material in suspension will reduce the light available for photosynthesis, the time available for net photosynthesis and, therefore, growth. Seagrass beds are located in areas that have natural fluctuations in light intensities and are able to cope with these changes. Seagrass can also store and mobilise carbohydrates and has been reported to be able to tolerate acute light reductions (below 2% of surface irradiance for two weeks) (Peralta *et al.*, 2002). However, seagrass beds are likely to be more intolerant to chronic increases in turbidity. Tolerance is intermediate and recoverability moderate. Sensitivity is therefore moderate.

Change in bio-chemistry: seagrasses need oxygen to supply their metabolism of both above and below ground tissue. Under normal circumstances, photosynthetically generated oxygen or water column oxygen is transported to roots and rhizomes by simple diffusion from the leaves to the roots via a well developed system of air tubes (lacunae) running through the plant. The presence of air spaces suggests that seagrass may be tolerant of low oxygen levels in the short-term. However, a prolonged reduction in oxygen levels, especially if combined with low light penetration and hence reduced photosynthesis may have an adverse effect. Inputs of organic matter consume oxygen in the water column and sediment. Long-term anoxic conditions that subsequently result from such inputs influence the metabolism of the plants resulting in poor energy availability and production of toxic metabolites, both of which may negatively affect growth and survival of the plants. Tolerance is low to long-term impacts and recoverability moderate. Sensitivity is therefore high.

Increased nutrient concentrations have been implicated in the continued decline of seagrass beds worldwide, either directly or due to eutrophication. Some harmful effects are listed below:

High nitrate concentrations causing meristems deterioration and metabolic imbalance; Increased growth of epiphytic algae leading to smothering; and Increased growth of blanketing algae and phytoplankton blooms causing and reduced light penetration and suffocation.

Phenolic compounds play an important role in providing seagrass with defence against infection, including wasting disease. Buchsbaum *et al.* (1990) found that the levels of phenolic compounds were lowered under conditions of nutrient enrichment, possibly due to a reduction in available carbon within the plant. Any nutrient enrichment could therefore increase vulnerability to disease, including wasting disease. Intolerance is high and recoverability low. Sensitivity is therefore high.

Change in coastal processes: a reduction in water flow could also increase sedimentation and smothering. These issues have been discussed separately in the previous section on sedimentation.

Infrastructure impacts: the loss of substratum will lead to the loss of the entire population within the footprint. A tolerance of low is recorded. The slow recovery of *Zostera* populations since the 1920s - 30s outbreak of wasting disease suggests that, once lost, eelgrass beds take considerable time to re-establish. However, Phillips & Menez (1988) reported that following displacement rhizomes and shoots can root and re-establish themselves if they settle on sediment http://www.marlin.ac.uk/glossaries/glossary.php?term=sediment long enough. Seagrass is not physically robust. Root systems are typically located within the top 20 cm of the sediment and so can be dislodged easily by a range of activities, including aquaculture. Some physical disturbance can, however, have positive consequences in certain circumstances. Rae (1979) found that small-scale disturbance encouraged new growth of intertidal seagrass in the Moray Firth. Overall, tolerance is low and recoverability low. Sensitivity is therefore high.

Visual land & seascape modification: there is no sensitivity with respect to this pressure.

Disturbance: there is no sensitivity with respect to noise. However, birds are major predators of mussels and several bird species are intolerant of noise. Potential indirect impacts associated with bird disturbance are discussed under predator control below.

Predator control: wildfowl can consume a large proportion of the available seagrass biomass. The feeding patterns of wildfowl can be heavily modified by shooting disturbance (Madsen, 1988). Some wildfowl are, however, intolerant of disturbance from noise. If disturbed this could lead to a reduction in grazing pressure. However, Nacken & Reise (2000) have also the inhibition of summer regrowth due to the removal of grazing. Overall, it is considered that there is low sensitivity with respect to this pressure.

Chemical use: Pollution arising from man-made chemicals, such as anti fouling agents, may in certain areas constitute a substantial problem to seagrass performance and survival. Overall, tolerance is low and recoverability low. Sensitivity is therefore high.

Pathogen transmission: Not relevant.

Inter-breeding with wild organisms: Not relevant.

Introduction of alien species: *Sargassum muticum* is a brown fucoid seaweed native to Oriental-Pacific coastline. It was first accidentally introduced into England and Northern France in the late 1960's with the import of Pacific oysters. In Europe it has spread widely, partly by residual currents and commercial oyster movements. Its ecological impact is considerable as it has colonised large areas of sheltered coastline and has been reported to replace native populations of seagrass. In addition, introduced species, such as the alga *Caulerpa* and the fan worm *Sabella spallanzanii,* can be competitors for soft bottom substratum. Tolerance is low and recoverability low. Sensitivity is therefore high.

Indirect ecosystem impacts: not relevant.

6.3 SANDBANKS, MUDFLATS AND SANDFLATS

6.3.1 Background

Sandbanks which are slightly covered by sea water all the time and mudflats and sandflats not covered by seawater at low tide are listed under Annex I of the Habitats Directive. The sensitivity of these habitats is relatively similar and so have been grouped together below.

Habitat description: these habitats can be divided into two basic types, those (i) which are slightly covered by sea water all the time and (ii) those not covered by seawater at low tide.

(i) Sandbanks which are slightly covered by sea water all the time. Clean sands, which occur in shallow water, either on the open coast or in tide-swept channels of marine inlets, typically lack a significant seaweed component and are characterised by robust fauna, particularly amphipods (*Bathyporeia*) and robust polychaetes including *Nephtys cirrosa* and *Lanice conchilega*. Non-cohesive muddy sand (with 5% to 20% silt/clay) in the infralittoral zone, support a variety of animal-dominated communities, particularly polychaetes (*Magelona mirabilis*, *Spiophanes bombyx* and *Chaetozone setosa*), bivalves (*Fabulina fibula* and *Chamelea gallina*) and the urchin *Echinocardium cordatum*. Moderately exposed habitats with coarse sand, gravelly sand, shingle and gravel are subject to disturbance by tidal steams and wave action. Such habitats found on the open coast or in tide-swept marine inlets are characterised by a robust fauna of infaunal polychaetes such as *Chaetozone setosa* and *Lanice conchilega*, cumacean crustacea such as *Iphinoe trispinosa* and *Diastylis bradyi*, and venerid bivalves.

(ii) Mudflats and sandflats not covered by seawater at low tide: Shores of clean, medium to fine and very fine sand, with no coarse sand, gravel or mud present, support a range of species including amphipods and polychaetes. On the lower shore, and where sediments are stable, bivalves such as *Angulus tenuis* may be present in large numbers.

Muddy sand or fine sand shores often occur as extensive intertidal flats on open coasts and in marine inlets. The sediment generally remains water-saturated during low water. The habitat may be subject to variable salinity conditions in marine inlets. An anoxic layer may be present below 5 cm of the sediment surface, sometimes seen in the worm casts on the surface. The infauna consists of a diverse range of amphipods, polychaetes, bivalves and gastropods.

Littoral mud typically forms extensive mudflats, though dry compacted mud can form steep and even vertical structures, particularly at the top of the shore adjacent to saltmarshes. Little oxygen penetrates these cohesive sediments, and an anoxic layer is often present within a few millimetres of the sediment surface. This habitat is generally found in sheltered bays or marine inlets and along sheltered areas of open coast. Typical species include a rich variety of polychaetes including *Melinna palmate*, tube building amphipods (*Ampelisca* sp.) and deposit feeding bivalves such as *Macoma balthica* and *Mysella bidentata*.

Ecological importance: subtidal mobile sandbanks provide prey for demersal fishes and are often important as fish nursery areas. The sandbanks are also important areas for crab populations, including predatory species. The epifaunal component may represent a large proportion of the biomass of the sand bank fauna with large numbers of echinoderms such as *Asterias rubens* and brittle stars such as *Ophiura albida*. Birds such as the guillemot, razorbill, scoter, puffin and the terns will feed on the fish such as sandeels (*Ammodytes* spp.) which are found in mobile subtidal sands (Batten *et al,* 1990). Intertidal sandflats, although generally low in species richness, also provide an important food resource for waterfowl.

Intertidal mudflats are important in the functioning of estuarine systems and may have a disproportionately high productivity compared to subtidal areas (Elliott & Taylor, 1989b). Conversely, coastal sandflats have a very poor productivity (McLachlan, 1996). Epifaunal organisms associated with these biotope complexes are predominantly mobile predatory species such as crabs e.g. *Carcinus maenus* and shrimps e.g. *Crangon crangon*, which feed on infaunal populations consisting of small bivalves, polychaetes and crustacea. Polychaete worms are dominant predators within the substratum and tend to be opportunistic and actively pursue prey. Many infaunal species also scavenge such as *Nephtys* and the isopod *Eurydice pulchra.* Shorebirds form important predators on NW European intertidal mud and sandflats during long migrations over long distances from breeding to wintering grounds. Particularly dependent species are Brent geese, shelduck, pintail, oystercatcher, ringed plover, grey plover, bar-tailed and black-tailed godwits, curlew, redshank, knot, dunlin and sanderling, whilst grey geese and whooper swan may use this habitat for roosting (Jones & Key, 1989; Davidson *et al,* 1991).

Intertidal areas act as juvenile fish feeding areas (Costa & Elliott, 1991). Mud and sandflats are important nursery areas for plaice (Lockwood, 1972; Marshall, 1995; Marshall & Elliott, 1997), as well as feeding areas for sea bass and flounder (Elliott & Taylor, 1989). Fish such as Dover sole, *Solea solea* and gadoids frequent sandy areas, but many also occur on coarser and mixed grades of sediment. The most important marine predators on intertidal sand and mudflats are particularly the flatfish *Solea solea* (sole), *Limanda limanda* (dab), *Platichthys flesus* (flounder) and *Pleuronectes platessa* (plaice) which feed on polychaetes and their tails (e.g. of *Arenicola* and *Nereis*), bivalve young and siphons (e.g. of *Macoma* and *Angulus*) and tidally active crustaceans such as *Bathyporeia* and *Eurydice* species (Croker & Hatfield, 1980; McDermott, 1983; McLachlan, 1983; Zwarts *et al,* 1985).

6.3.2 Sensitivity Assessment

Sedimentation: increased sedimentation will alter the make-up and diversity of communities. Animals burrowing in sediments that receive normal detrital inputs comprise a diverse fauna of many species and include a wide range of higher taxa, body sizes and functional types.

Karakassis *et al.* (2000) have determined that organic inputs increased 2-3 fold below and adjacent to fish farms. With organic enrichment, this diversity also initially increases as the enhanced food supply provides opportunities for the expansion of existing populations and the immigration of new species. However, deterioration of the physical and chemical conditions in the sediments progressively eliminates the larger, deeper-burrowing and longer-lived forms favouring smaller, rapidly growing opportunist species. With increasing inputs, the surface sediments become anoxic and only a small number of specialist taxa can survive, mainly small annelid and nematode worms, which may flourish in huge numbers. Where anaerobic processes occur close to the sediment surface, this may become covered in dense white mats of sulphide oxidising bacteria Beggiatoa sp. High flow rates, bringing a continuous supply of oxygen to the sediment surface, do allow the survival of infauna even when the sedimentary surface layer is anoxic but, where sediments suffer oxygen deficiency for even relatively short periods of a few hours, e.g. caused by slack water, large sections of the benthic macrofauna are eliminated. Ultimately, increasing levels of sedimentary oxygen demand bring about anoxia in the lower levels of the overlying water column leading to the elimination of all higher life (SECRU, 2002). Following cessation of aquaculture practice it may take a couple of years for communities to return to normal (SECRU, 2002). Overall, tolerance is low and recoverability intermediate. Sensitivity is therefore high.

Increased turbidity associated with more material in suspension (e.g. algae resulting from nutrient enrichment, organic material etc), may impact upon floral biomass. It is, however, expected that flora would be able to cope with short-term changes. The sensitivity of communities would be higher in sheltered areas. Generally, tolerance is intermediate and recoverability moderate. Sensitivity is therefore moderate.

Change in bio-geochemistry: changes in oxygenation may affect the make up of subtidal habitats, particularly related to floral biomass. Sensitivity is dependent upon floral species present, but overall can be expected to be high.

The effects of organic enrichment on sedimentary systems are discussed under sedimentation above where sensitivity is regarded as high.

Change in coastal processes: sandflats and sandbanks are highly mobile and infauna and epifauna are well adapted to changing hydrography, i.e. they are able to re-burrow rapidly following wash-out during extreme storm events. Intolerance is low and recoverability very high. A reduction in water flows can lead to increased sedimentation, particularly in low energy systems. This will lead to effects as discussed under sedimentation above. Overall, sensitivity to a change in coastal processes alone is considered to be low.

Infrastructure impacts: substratum loss will lead to a loss of available habitat within the footprint. A tolerance of low is recorded. Recoverability is dependent upon species present, but at worst recoverability should be moderate. Sensitivity is therefore high.

Physical disturbance can potentially have an effect on the integrity of sediment habitats. This in turn, could impact upon predator species, e.g. wildfowl. However, regeneration of species diversity will occur reasonably quickly and natural sedimentation will recover sediment structure in the short to medium term if operations cease. Crustacea communities will be most sensitive to physical disturbance. Tolerance and recoverability is dependent upon species present, but overall sensitivity is expected to be moderate.

Table 30: Impacts of Shellfish Aquaculture on Estuarine Mudflats and Sandflats

Fishery	Methods	Potential effects
Cockle	Tractor towed dredge Hydraulic dredge	• Intertidal dredge tracks visible for varying amounts of time, i.e. months in stable sediments, a tide in mobile sediments. • Sediment layers may be altered causing erosion to cockle bed. • Significant reduction in biomass of target and non target species immediately after fishing operation. Likely to be more pronounced with extended recovery times, i.e. many months, in areas with diverse communities and stable conditions.
Oysters mussels and Clams	Dredge	• Sub-tidal and intertidal dredge tracks visible for varying amounts of time, ie. months in stable sediments, hours in mobile sediments. • Top 10-15 cm of substrate disturbed and sediment plumes created • Change in benthic flora and fauna as a consequence of repeated dredging.
	Hand gathering	• Holes and tailings left on the intertidal visible for varying amounts of time, ie. months in stable sediments, a tide in mobile sediments. • Under size target species damaged or exposed to predation, desiccation or freezing.
Scallops	Scallop dredge	• Dredge tracks visible for varying amount of time, ie. days or months. In stable conditions a relatively minor fishery may have a significant cumulative effect on bottom micro topography. • Top 60 -100 mm of substrate disturbed. • Re-suspension of sediment. • Significant reduction in biomass of target and non target species immediately after fishing operation. Likely to be more pronounced with extended recovery times, i.e. many months, in areas with diverse communities and stable conditions. • Maerl crushed, smothered and killed. • Associated biota of Maerl either caught, damaged or smothered by resuspended sediment.

Fishery	Methods	Potential effects
Razor shell	Hydraulic dredge	• Sub-tidal dredge tracks, deeper than a conventional hydraulic cockle dredge (e.g. 0.5 - 3.5 m wide, 0.25 - 0.6 m deep). Visible for weeks/months in mobile sediments. • Substantial physical disturbance of substrate • Significant reduction in abundance of non-target species immediately after fishing operation. Weeks/months to recover to pre fishing levels in mobile sediment.
Salmon cages		• Smothering of benthic communities with faecal and waste food. • Anoxic conditions underneath cage. • Raised levels of dissolved gases, hydrogen sulphide, ammonia. • Sub-lethal effects of chemical disease and sea lice treatments on lug worm.
Shellfish cultivation		• Increased sedimentation and effects on infauna beneath mussel cultures. • Manila clam cultivation in lays increases density of benthic species, changes in infauna and increased sedimentation. • Harvesting with hand raking reduces species diversity and abundance by 50 %, suction dredging reduces species abundance by 80-90%. Recovery to pre-harvesting levels may take long periods e.g.. 7 months. • Trenching up to 10 cm deep, may take months to fill e.g.. 4 months in one study. • Accidental introduction of alien species.

Visual land & seascape modification: not relevant.

Disturbance: it is unlikely that noise will have an adverse effect on habitats. Wildfowl, however, are intolerant of disturbance from noise, which could lead to reduced feeding pressure. Overall, it is considered that there is no direct sensitivity with respect to this pressure.

Predator control: predator disturbance could affect feeding on species within sand and mud communities. This could have both positive or negative impacts. Tolerance is, however, high and recoverability moderate. Sensitivity is therefore low.

Chemical use: in general, it is probably true to say that the greater dispersive characteristics of high energy sites are beneficial in ameliorating the impact of chemical treatments. Sites with restricted exchange (lagoons) can be considered most vulnerable. The impact of chemical use is therefore dependent upon local physical conditions and species present. However, given the ability of sediments to accumulate contaminants and potential for toxicity, it is considered that tolerance at unregulated levels would be low and recoverability low. Sensitivity is therefore high.

Pathogen transmission: as discussed in other sections.

Inter-breeding with wild organisms: not relevant.

Use of alien species: the introduction of alien species, such as Sargassum muticum could effect the distribution of native floral species, e.g. seagrass (see Seagrass section above) if present on sublittoral sediments. Overall, intolerance is low and recoverability high. Sensitivity is therefore low.

Indirect ecosystem impacts: not relevant.

6.4 MAERL BEDS

Maerl beds are discussed here as they can constitute an important community in coastal lagoons and large shallow inlets and bays, which are listed in Annex I of the Habitats Directive.

6.4.1 Background

Habitat description: beds of maerl in coarse clean sediments of gravels and clean sands occur either on the open coast or in tide-swept channels of marine inlets (the latter often stony). In fully marine conditions the dominant maerl is typically *Phymatolithon calcareum*, whilst under variable salinity conditions in some sea lochs beds of *Lithothamnion glaciale* may develop. Live maerl beds in sheltered, silty conditions are dominated by *Lithothamnion corallioides* with *Phymatolithon calcareum* and *Phymatolithon purpureum*. Species of seaweed, anemones, polychaetes, isopods are also often present.

Ecological importance: maerl beds in general are a particularly diverse habitat with over 150 macro algal species and 500 benthic faunal species recorded (Birkett *et al*., 1998). The loose structure of these beds permits water circulation and oxygenation to a considerable depth. As a consequence of this loose structure, maerl provides shelter for a wide variety of fauna.

6.4.2 Sensitivity Assessment

Sedimentation: The detrital rain from the fish farm cages could act in a similar way to terrigenous silt, reducing light penetration through the water column and smothering the maerl surface so that the stabilizing epiphytic algae could no longer establish themselves. Even if recolonisation occurs, with the slow growth rates of coralline algae, it will take a very long time to re-establish a similar population although this may be faster for *Lithothamnion glaciale* than for other maerl species (Irvine & Chamberlain, 1994). Tolerance is low and recoverability low. Sensitivity is therefore high.

Increased turbidity will reduce the light available for photosynthesis, the time available for net photosynthesis and, therefore, growth. Tolerance is intermediate and recoverability moderate. Sensitivity is therefore moderate.

Change in bio-chemistry: anoxia will kill live maerl, but exposure to low oxygen concentrations for a week may not kill the plants. Respiration, growth and reproduction may be affected by hypoxia but the effects are likely to be short term on return to normal oxygen concentrations. Tolerance is low and recoverability moderate. Sensitivity is therefore high.

Increased nutrient levels in the water column can result in the excessive growth of ephemeral species of macroalgae. Eutrophication also causes increased turbidity of the coastal water due to more prolific growth of phytoplankton. Both these effects could result in damage to maerl biotopes. Heavy overgrowth of epiphytic algae would reduce light levels available to the maerl, presumably reducing growth rates, as would increased turbidity from planktonic blooms. In addition, the macroalgal overgrowths and phytoplankton might compete with the maerl for selected nutrients. Tolerance is low and recoverability moderate. Sensitivity is therefore high.

Change in coastal processes: reduced water flow could allow greater build up of deposited particulate matter effectively covering the algae and restricting photosynthesis. The very slow growth rate of maerl means that vegetative regeneration will take a long time. Tolerance is intermediate and recoverability low. Sensitivity is therefore moderate.

Infrastructure impacts: the loss of substratum will lead to the loss of the entire population within the footprint. Physical disturbance may break up loose-lying maerl nodules or highly branching crustose plants into smaller pieces resulting in easier displacement by wave action. Once a population has become extinct, the lack of propagules means that it is unlikely that it will be re-established. Even if reproductive propagules arrive from elsewhere, with the very slow growth rate of maerl, it will take a very long time to re-establish a similar population. Tolerance is therefore low and recoverability low. Sensitivity is therefore high.

Visual land & seascape modification: not relevant.

Disturbance: there is no sensitivity with respect to this pressure.

Predator control: not relevant.

Chemical use: insufficient information is available to determine the sensitivity.

Pathogen transmission: not relevant.

Inter-breeding with wild organisms: not relevant.

Introduction of alien species: the introduced species *Crepidula fornicata* (Slipper Limpet) has radically altered the ecology of maerl beds in the Rade de Brest, France through increasing siltation and provision of substrata (J. Hall-Spencer pers. comm.). It competes with other filter-feeding invertebrates for food and space, and in waters of high concentrations of suspended material it encourages deposition of mud owing to the accumulation of faeces and pseudofaeces (Barnes, Coughlan & Holmes 1973). Intolerance is high and recoverability very low. Sensitivity is therefore high.

Indirect ecosystem impacts: not relevant.

6.5 KELP AND SEAWEED COMMUNITIES

Kelp and seaweed communities are discussed here as they can constitute an important community in, estuaries, coastal lagoons and large shallow inlets and bays, which are listed in Annex I of the Habitats Directive.

6.5.1 Background

Habitat description: infralittoral rock typically has an upper zone of dense kelp (forest) and a lower zone of sparse kelp (park), both with an understorey of erect seaweeds. In exposed conditions the kelp is *Laminaria hyperborea* whilst in more sheltered habitats it is usually *Laminaria saccharina*; other kelp species may dominate under certain conditions. On the extreme lower shore and in the very shallow subtidal (sublittoral fringe) there is usually a narrow band of dabberlocks *Alaria esculenta* (exposed coasts) or the kelps *Laminaria digitata* (moderately exposed) or *L. saccharina* (very sheltered). Areas of mixed ground, lacking stable rock, may lack kelps but support seaweed communities. In estuaries and other turbid-water areas the shallow subtidal may be dominated by animal communities, with only poorly developed seaweed communities.

Ecological importance: although kelp species often dominate their environment, they also supply extra substrate available for other organisms. Any kelp-bearing area will contain a number of habitats available for other biota. The faunal diversity of kelp biotopes is extremely rich owing to the available primary, secondary and microbally recycled production and also to the structural diversity within the habitat with many various exploitable niches available. The floral diversity within kelp communities is also great with colonisation occurring epiphytically on kelp plants or less independently on the surrounding substrata. Urchin predators such a lobsters *Homarus gammarus* and wolf fish *Anarhichas lupus* may also be found amongst kelp forests.

6.5.2 Sensitivity Assessment

Sedimentation: the impact of sedimentation on kelp was studied by Lyngby & Mortensen (1996). They recorded that deposition of a 1-2 mm thick layer of fine-grained material on the plants caused direct physical damage and rotting and as a result, 25% of the plants died after 4 weeks. On return to normal conditions recovery should be high because the species has been observed to rapidly recruit to cleared areas of the substratum (Kain, 1975). Tolerance is low and recoverability moderate. Sensitivity is therefore high.

An increase in the level of suspended sediment was found to reduce growth rates in *Laminaria saccharina* by 20% (Lyngby & Mortensen, 1996). Burrow & Pybus (1971) found that the mean breadths of thalli of *Laminaria saccharina* that had grown in the silted waters of Redcar, Souter Point and Robin Hood's Bay (North-East England) were significantly smaller than those grown in the clearer waters of St Abbs (North-East England) and Port Erin (Isle of Man). Tolerance is low and recoverability moderate. Sensitivity is therefore high.

Change in bio-geochemistry: kelp and seaweeds need oxygen for photosynthesis. A prolonged reduction in oxygen levels, especially if combined with low light penetration and hence reduced photosynthesis may have an effect. Inputs of organic matter consume oxygen in the water column and sediment. Tolerance is low to long-term impacts and recoverability moderate. Sensitivity is therefore high.

A slight increase in nutrient levels may enhance the growth of kelp, but in excess it may be detrimental. The effects of eutrophication on the species have been studied by Conolly & Drew (1985) on the east coast of Scotland. Plants at most the eutrophic site, where nutrient levels were 25% higher than average, exhibited higher growth rates suggesting that growth is nutrient limited. However, higher organic content could lead to increased growth of epiphytic algae leading to smothering and blanketing algae and phytoplankton blooms causing and reduced light penetration and suffocation. Tolerance is low and recoverability intermediate. Sensitivity is therefore high.

Change in coastal processes: a decrease in the level of water flow is unlikely to have a detrimental effect because the species often grows in areas of low water movement where it may form extensive loose-lying populations (Burrows, 1958). However, further reduced water flows could lead to increased sedimentation, for which there is high sensitivity recorded.

Infrastructure impacts: the loss of substratum will lead to the loss of the entire population within the footprint. However, the species rapidly colonises cleared areas of the substratum. Burrows (1958) concluded that it is possible that a few individuals could survive displacement in suitable conditions. The fronds of kelp are relatively soft so could be damaged by physical disturbance. Recovery should be high because the species rapidly colonises cleared areas of the substratum. Tolerance is low and recoverability high. Sensitivity is therefore moderate.

Visual land & seascape modification: not relevant.

Disturbance: not relevant.

Predator control: not relevant.

Chemical use: insufficient information is available to determine sensitivity.

Pathogen transmission: not relevant.

Inter-breeding with wild organisms: not relevant.

Introduction of alien species: the increase in non-native marine species, introduced principally by aquaculture and in ballast water, is causing concern in Europe. One introduction of potential significance to kelp biotopes is the Japanese kelp, *Undaria pinnatifida* (wakame). This species has recently spread to the south coast of England from northern Brittany, where it was introduced for aquaculture, and it is thought likely to compete with the native *Saccorhiza polyschides*. The brief introduction of *Macrocystis pyrifera* to French waters in the 1970s, which was stopped by international pressure, could have had disastrous effects on all the native kelps and their associated biotopes. *Macrocystis* fronds can reach 60m in length, and a single frond can gain 36g per day, and thus would have competed with native species for space, light and nutrients. Tolerance is low and recoverability low. Sensitivity is therefore high.

Indirect ecosystem impacts: not relevant.

6.6 SALTMARSH COMMUNITIES

Atlantic and continental salt marshes are listed under Annex I of the Habitats Directive and as such are important habitats that warrant discussion here.

6.6.1 Background

Habitat description: saltmarsh occurs in sheltered, low energy habitats where sediment has built up above mean high water of neap tides (MHWN) and to dry out between high neap tides. Saltmarsh plants stabilise and consolidate accreting sediment allowing saltmarsh to increase in height over time. Dynamic changes, occasional events such as storms and disturbance, and succession, provide a complex habitat for a diverse species assemblage. As accretion causes the saltmarsh to grow upwards in relation to tidal height, seawater influence decreases and the invertebrate fauna, halophytic and algal flora changes. With increasing distance from the sea the fauna and flora change from mainly marine in the lower and pioneer marsh and creeks or pans to mainly terrestrial in origin in the mid to high marsh.

Ecological importance: saltmarshes provide a diverse habitat for a wide range of flora and fauna, including birds, algae, bacteria, fungi, insects, oligochaetes, polychaetes and suspension feeding invertebrates, arachnids and mammals.

6.6.2 Sensitivity Assessment

Sedimentation: saltmarsh is a sedimentary habitat dependant on deposition and erosion of sediment. Therefore, most communities and associated species are well adapted to levels of sedimentation and occasional smothering. Tolerance is high and recoverability high. Sensitivity is therefore low.

Change in bio-geochemistry: saltmarshes are subject to constant changes in the level of inundation as the tide transgresses and recedes. The level of sensitivity is dependent upon topography and the transition zone in which communities sit. Vascular plants liberate oxygen through photosynthesis and are uncovered for the majority of the tidal cycle. Most infaunal polychaetes and oligochaetes are probably tolerant of low oxygen conditions, while some species of oligochaete and nematode may be dependant on the locally oxygenated areas around the roots of vascular plants. Tolerance is high and recoverability high. Sensitivity is therefore low. Moderate enrichment with nutrients may be beneficial to both plant and infaunal communities. Holt *et al.* (1995) suggested care should be taken when applying this conclusion in all salt marshes. Increased nutrient levels have been associated with increased algal mats, which may smother some burrowing species. (Packham & Willis, 1997). Tolerance is high and recoverability high. Sensitivity is therefore low.

Change in coastal processes: salt marshes develop in sheltered environments where sediments accumulate. Reduced water flow rate could increase the deposition of sediments and lead to saltmarsh building. Overall, there is low sensitivity to this pressure.

Infrastructure impacts: loss of substratum will remove the vascular plants, algal mats, infauna and their associated community within the footprint. Recovery will depend on recruitment of the plant communities and their invertebrate fauna http://www.marlin.ac.uk/glossaries/glossary.php?term=fauna. Tolerance is low and recoverability intermediate. Sensitivity is therefore moderate. Physical disturbance can potentially have an effect on the integrity of sediment habitats. This in turn, could impact upon predator species, e.g. wildfowl. However, regeneration of species diversity will occur reasonably quickly and natural sedimentation will recover sediment structure in the short to medium term if operations cease. Some physical disturbance could be beneficial to plant species through facilitating seed dispersal. Tolerance is intermediate and recoverability high. Sensitivity is therefore moderate.

Visual land & seascape modification: not relevant.

Disturbance: it is unlikely that noise will have an adverse effect on habitats. Wildfowl, however, are intolerant of disturbance from noise, which could lead to reduced feeding pressure. Removal of predators may allow some species to dominate, enable recruitment of others and affect the community http://www.marlin.ac.uk/glossaries/glossary.php?term=community structure. Overall, it is considered that there is no direct sensitivity with respect to this pressure.

Predator control: predator disturbance could affect bird species feeding on invertebrates within sand and mud communities. This could have both positive or negative impacts. Intolerance is, however, low and recoverability moderate. Sensitivity is therefore low.

Chemical use: sheltered, low energy areas in enclosed bays or estuaries act as a sink for sediment and contaminants. The sub-lethal or toxic effects vary with concentration, the bio-availability of the contaminant, and the physiology of the affected organism. Insufficient information is available to determine the effects of aquaculture on saltmarsh communities. However, given the ability of sediments to accumulate contaminants and potential for toxicity, it is considered that tolerance at unregulated levels would be low and recoverability low. Sensitivity is therefore likely to be high.

Transmission of disease and parasites: insufficient information is available, but it is highly unlikely that saltmarsh communities would be affected by the transmission of disease and parasites from aquaculture operations.

Inter-breeding: not relevant.

Use of exotic species: not relevant.

Indirect ecosystem impacts: not relevant.

6.7 SAND DUNE COMMUNITIES

Sea dunes of the Atlantic, North Sea and Baltic coasts are listed under Annex I of the Habitats Directive and as such are important habitats that warrant discussion here.

6.7.1 Background

Habitat description: coastal sand dunes develop where there is an adequate supply of sand (sediment particle size ranges from 0.2 to 2.0 mm) in the intertidal zone and where onshore winds are prevalent. The critical factor is the presence of a sufficiently large beach plain whose surface dries out between high tides. The dry sand is then blown landwards and deposited above high water mark, where it is trapped by specialised dune-building grasses which grow up through successive layers of deposited sand.

Sand dune vegetation forms a number of zones. Embryonic and mobile dunes occur mainly on the seaward side of and support very few plant species, the most characteristic being marram grass *Ammophila arenaria*. Semi-fixed dunes occur where the rate of sand accretion has slowed but the surface is still predominantly bare sand; marram is still common but there is an increasing number of other species. Fixed dune grassland forms largely closed swards where accretion is no longer significant, the surface is stabilised and some soil development has taken place. Calcareous fixed dunes support a particularly wide range of plant species. On dunes which have become acidified by leaching, acid dune grassland or dune heaths develop. Dune heaths are usually dominated by heather *Calluna vulgaris*. Acidic dunes which are heavily grazed by rabbits may support lichen communities. Dune slack vegetation occurs in wet depressions between dune ridges; it is often characterised by creeping willow *Salix repens* sp *argentea* and a number of mosses. Fixed dunes and dune heath are particularly threatened habitats and are regarded as priorities under the EC Habitats Directive (UK BAP, 1999).

Ecological importance: saltmarshes provide a diverse habitat for a wide range of rare and important flora and fauna, including bird, vascular plant, fungi, insect and mammal species.

6.7.2 Sensitivity Assessment

Sedimentation: sand dune habitats are sedimentary habitat and dependent on deposition of sediment. Increased sedimentation offshore will potentially provide additional material for deposition on the shore and onto sand dune complexes. However, sand dune systems are not dependent upon fine organic material and any increased sedimentation for aquaculture activities will not have any implication on sand dune communities. There is therefore no sensitivity with respect to this pressure.

Change in bio-geochemistry: not relevant.

Change in coastal processes: unless artificially constrained, the seaward edges of sand dunes can be a highly mobile feature, though there is a natural trend to greater stability further inland. Insufficient sand supply is the key issue for causing sand dune habitat degradation. Therefore any processes that restrict sediment supply could lead to a loss of sand dunes, particularly for eroding dune systems. Tolerance is low and recoverability moderate. Sensitivity is therefore moderate.

Infrastructure impacts: loss of substratum will remove the area available for colonisation by flora and fauna within the footprint. Recovery will depend on recruitment of the plant communities and the adjacent area available for colonisation by fauna http://www.marlin.ac.uk/glossaries/glossary.php?term=fauna. Tolerance is low and recoverability moderate. Sensitivity is therefore moderate.

Physical disturbance can potentially have an effect on the integrity of sand dune habitats, particularly fixed dune systems, which are less exposed to natural erosion. This in turn, could impact upon species. However, regeneration of species diversity will occur reasonably quickly and natural sedimentation will recover sediment structure in the short to medium term if operations cease.

Visual land & seascape modification: not relevant.

Disturbance: not relevant.

Predator control: predator disturbance could affect bird species within sand dune communities, particularly ground nesting birds. Intolerance is, however, intermediate and recoverability moderate. Sensitivity is therefore moderate.

Chemical use: insufficient information is available to determine sensitivity with respect to this pressure. However, contaminants are not easily bound to sand particles and therefore sensitivity is considered to be low.

Pathogen transmission: not relevant.

Inter-breeding with wild organisms: not relevant.

Introduction of alien species: not relevant.

Indirect ecosystem impacts: not relevant.

6.8 SHINGLE COMMUNITIES

Vegetated shingle beaches are listed under Annex I of the Habitats Directive and as such are important habitats that warrant discussion here.

6.8.1 Background

Habitat description: shingle is defined as sediment with particle sizes in the range 2 to 200 mm. The vegetation communities of shingle features depend on the amount of finer materials mixed in with the shingle, and on the hydrological regime. Some are well sorted and consist entirely of pebbles, while others are poorly sorted and may also contain sand and/or boulders. Most shingle shores become coarser towards the upper end of the beach. The classic pioneer species on the seaward edge include sea kale *Crambe maritima*, sea pea, *Lathyrus japonicus,* Babington's orache*, Atriplex glabriuscula,* sea beet, *Beta vulgaris,* and sea campion *Silene uniflora*; such species can withstand exposure to salt spray and some degree of burial or erosion (UK BAP, 1999). In addition, shingle can be important for many invertebrate species.

Ecological importance: shingle structures may support breeding birds including gulls, waders and terns. Diverse invertebrate communities are found on coastal shingle, with some species restricted to shingle habitats (UK BAP, 1999).

6.8.2 Sensitivity Assessment

Sedimentation: shingle beaches are a sedimentary habitat dependant on deposition and erosion of sediment. Therefore, most communities and associated species are well adapted to levels of sedimentation and occasional smothering. Tolerance is high and recoverability high. Sensitivity is therefore low.

Change in bio-geochemistry: not relevant.

Change in coastal processes: shingle structures are dependent upon exposure to waves and tides, which vary in strength. Given that they are located in exposed environments small reductions in current velocity should have no impact. There is therefore no sensitivity with respect to a change in coastal processes.

Infrastructure impacts: loss of substratum will remove the area available for colonisation by flora and fauna within the footprint. Recovery will depend on recruitment of the plant and invertebrate communities and adjacent are available for colonisation http://www.marlin.ac.uk/glossaries/glossary.php?term=fauna. Tolerance is low and recoverability moderate. Sensitivity is therefore moderate.

Shingle structures are subject to high exposure to waves and physical movement.

Physical disturbance could lead to a loss of surface communities. Significant disturbance may take some time for natural processes to reinstate the environment. The period of recovery is of course dependent upon the scale of disturbance. Tolerance is high and recoverability moderate. Sensitivity is therefore moderate.

Visual land & seascape modification: not relevant.

Disturbance: not relevant.

Predator control: predator disturbance could affect bird species feeding on invertebrates within shingle communities. Intolerance is, however, low and recoverability high. Sensitivity is low.

Chemical use: insufficient information is available to determine sensitivity to this pressure.

Pathogen transmission: insufficient information is available, but it is highly unlikely that shingle communities would be affected by aquaculture.

Inter-breeding with wild organisms: not relevant.

Introduction of alien species: not relevant.

Indirect ecosystem effects: not relevant.

6.9 CETACEANS

6.9.1 Background

Species description: cetaceans are divided into two sub-orders: the odontocetes and the mysticetes. The odontocetes include the dolphin and porpoise which are common in shallow coastal waters and therefore comprise those species that may be impacted on by aquaculture developments. The bottlenose dolphin and harbour porpoise are two of the thirty five species of whales and dolphins which have been recorded in European seas. The harbour porpoise is common and widely distributed in inshore waters, while bottlenose dolphins are largely recorded in near shore waters and common dolphins in inshore and offshore waters. Other species sighted in close conjunction with fish farm sites in Scotland include white beaked dolphins, killer whales and the Minke whale (the latter being the most commonly sighted baleen whale in the region) (Marine Harvest, 2003).

Species importance: cetaceans are protected in European waters under Article 12 of the EC Habitats Directive (92/43/EEC), implemented by The Conservation (Natural Habitats, etc.) Regulations, 1994. These species are further protected by those EU countries that are signatories to the Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas (ASCOBANS), which include the requirement of signatories to 'work towards….the prevention of…disturbance, especially of an acoustic nature'.

6.9.2 Sensitivity Assessment

Sedimentation: potential impacts from sedimentation could occur indirectly to cetaceans through habitat degradation. However, due to the mobile nature of these species and the relatively small footprint of aquaculture sites, it is unlikely that cetaceans will significantly impacted by sedimentation. There is therefore no sensitivity with respect to sedimentation.

Change in bio-geochemistry: not relevant.

Change in coastal processes: not relevant.

Infrastructure impacts: potential impacts from the presence of aquaculture sites could occur indirectly to cetaceans through possible behavioural responses of cetaceans from disturbances in and around the farm, for example from the increased boating activity. However, due to the mobile nature of these species and the relatively small footprint of aquaculture sites, it is unlikely that cetaceans will significantly impacted by infrastructure impacts. There is therefore no sensitivity with respect to infrastructure impacts.

Visual land & seascape modification: not relevant.

Disturbance: small cetaceans generally have poor hearing at low frequencies (Vella *et al.* 2001). For example, the hearing range of the harbour porpoise ranges from 1kHz to 150kHz, whereby at the lower range of 1kHz, a noise source must be greater than 75dB to be audible to a porpoise (Vella *et al.* 2001). Noise impacts on cetaceans have historically been studied with regard to seismic surveys, which are nosier activities than would be associated with aquaculture operations. The general reaction of cetacean species to seismic surveys is avoidance (Vella *et al.* 2001). Increases in background noise can interfere with acoustic communication in cetaceans, thereby reducing the distance over which such communication can take place (http://www.snh.org.uk/pdfs/trends/seas/SeasAroundScotland.pdf).

Acoustic Deterrent Devices (ADDs) impacts on cetacean species are largely not as well known as with seals. Cetaceans are much more sensitive to acoustic noise and a high pitched sound that might inconvenience a seal might cause pain to a cetacean. Thus it is likely that powerful acoustic deterrents exclude cetaceans from a larger area than with seals. For example, a Canadian study indicated that killer whales were excluded from a 10 km radius of such a device (http://www.eurocbc.org/page489.html). More complex acoustic systems further aim to reduce impacts to marine mammals by 'ramping up' from a low noise level to reduce the chance of hearing loss in mammalian predators (http://www.rcep.org.uk/fisheries/Chapter6.pdf). Tolerance to noise sources is likely to be low and recoverability is high. Sensitivity is therefore moderate.

Predator control: underwater netting (on sides and occasionally bottoms) may be used to protect farmed fish from diving birds and marine mammals. Mortalities are associated with entanglement and subsequent death of seals and cetaceans in these nets. Scaring devices (usually acoustic) can also be used against dolphins and other cetaceans, which are reported to be effective for up to two years, though the effect appears to reduce over time (http://www.rcep.org.uk/fisheries/Chapter6.pdf). Long-term impacts of Acoustic Deterrent Devices (ADDs) on marine mammals are not conclusively known, although likely to be significant, see discussion above under 'Disturbance'. ADDs have been linked to declines of baleen and killer whales, leading to a ban on their use in British Columbia, Canada (http://www.rcep.org.uk/fisheries/Chapter6.pdf). Tolerance to predator control measures is low and recoverability is low, sensitivity is therefore high.

Chemical use: a wide variety of chemicals are used on fish farms through the use of sea-lice treatment medicines and anti-foulants based on metals. In general, the impacts of chemical pollution on cetaceans range from direct physical poisoning to degradation of important habitats.

The chemicals that are probably of most concern for cetaceans are the persistent organic pollutants (POPs) including pesticides, such as DDT, and industrial chemicals (e.g. polychlorinated biphenyls (PCBs)). These substances are more soluble in fat than in water, thereby accumulating at high levels in marine mammals that rely on blubber as an energy store. At critical concentrations, an interaction with an animal's hormonal system may occur, resulting in reduced reproductive performance and disease resistance (http://www.snh.org.uk/pdfs/trends/seas/SeasAroundScotland.pdf). Use of copper-based antifoulants is currently the standard global practice, however, there has been little evidence that copper is transmitted through the food chain, as it is present in an organic form that is not directly toxic (http://www.rcep.org.uk/fisheries/Chapter6.pdf). Tolerance to the use of chemicals is intermediate and recoverability is intermediate, sensitivity is therefore moderate.

Pathogen transmission: not relevant.

Inter-breeding with wild organisms: not relevant.

Introduction of alien species: not relevant.

Indirect ecosystem impacts: not relevant.

6.10 PINNIPEDS

6.10.1 Background

Species description: there are three species of seal (grey seal, common seal and harbour seal) that have been implicated with impacts from aquaculture activities in European waters. Grey seals generally have a coastal distribution, though they are known to travel considerable distances. Grey seals tend to live in rocky wave exposed sites and form large breeding aggregations on land during autumn. Common seals favour more sheltered inshore areas using islands and sand banks as haul out sites, staying in the same general area to breed, feed and rest, and do not form as large breeding colonies as grey seals (http://www.ukmarinesac.org.uk/activities/fisheries/f2_1.htm). Throughout Europe and the UK, harbour seal numbers have rapidly returned or now exceed their pre-Phocine distemper virus (PDV) epidemic levels from 1988. Between 1996 and 2001, approximately 29,700 harbour seals were counted in Scotland out of a total of 33,700 individuals in England and Scotland combined.

Species importance: both the common and grey seals are protected under Annex II of the EC Habitats Directive (92/43/EEC).

6.10.2 Sensitivity Assessment

Sedimentation: potential impacts from sedimentation could occur indirectly to seals through habitat degradation. However, due to the mobile nature of these species and the relatively small environmental footprint of aquaculture sites, it is unlikely that seals will significantly impacted by sedimentation. There is therefore no sensitivity with respect to sedimentation.

Change in bio-geochemistry: not relevant

Change in coastal processes: not relevant

Infrastructure impacts: potential impacts from the presence of aquaculture sites could occur indirectly to seals through possible behavioural responses from disturbances in and around the farm as a result of increased boating activity. However, due to the mobile nature of these species and the relatively small footprint of aquaculture sites, it is unlikely that seals will significantly impacted by infrastructure impacts. There is therefore no sensitivity with respect to infrastructure impacts.

Visual land & seascape modification: not relevant

Disturbance: in general, seals show avoidance reactions to noise. However, it is likely that seals will quickly habituate to noise (Westerberg, 1999). Tolerance to noise sources is likely to be low and recoverability is high. Sensitivity is therefore moderate.

Predator control: predation on fish stocks by common seals and grey seals is well known and many farms employ measures to discourage seals from charging their nets and stressing farmed stock. These include permanent devices, such as false cage bottom nets (typically of 50 mm mesh) that are integrated into the cage nets, as well as intermittent devices, such as submerged ultrasonic seal scarers (Fish Vet Group, 2004). In addition, other deterrents such as pursuit with boats, lights, underwater explosive crackers and emetics to induce conditioned food aversion are also used to reduce the number of seal attacks (Heffernan, 1999).

Exclusion of seals from the vicinity of the fish pens with physical barriers they cannot penetrate has been deemed one of the most successful methods of deterrent and includes perimeter fences and protection nets made of steel mesh set around individual pens. However, this method may result in mortalities from capture in such anti-predator nets set around salmon farms.

An estimated 80% of fish farms in Scotland are known to be predated by seals (Beveridge, 2001). The number of seal attacks appears to peak in winter post breeding and post moulting. Acoustic Deterrent Devices (ADDs) are reportedly effective for up to two years, though the effect appears to diminish with time. This is especially so with seals that tend to learn that these intense signals can be withstood (http://www.rcep.org.uk/fisheries/Chapter6.pdf). Although some studies have shown that seals and sea lions are not deterred by ADDs, these species may experience hearing damage at close range. Further, these sounds may also interfere with communication signals between animals and with passive listening abilities (http://www.rcep.org.uk/fisheries/Chapter6.pdf).

In the UK, fish farm operators are permitted to shoot seals, under the Conservation of Seals Act 1970, to prevent damage to their nets or any fish within them. Although it is difficult to assess the impact of this to seal populations, it is likely to be localised and limited in extent but could have a significant effect on local populations (http://www.ukmarinesac.org.uk/activities/fisheries/f2_1.htm). However, this has been shown not to have a detrimental effect on UK seal populations.

Tolerance to the various predator control measures is therefore considered to be high and recoverability is high. Overall sensitivity is low.

Chemical use: a wide variety of chemicals are used on fish farms through the use of sea-lice treatment medicines and anti-foulants based on metals. The impacts of chemical pollution on seals range from direct physical poisoning to degradation of important habitats. However, there is little literature that discusses the impacts from specific chemicals used in aquaculture and their potential impacts to marine mammals. The chemicals that are of most concern for seals include those described for cetaceans and accumulate in seal blubber in the same way leading to a reduction in reproductive performance and in disease resistance (http://www.snh.org.uk/pdfs/trends/seas/SeasAroundScotland.pdf). Tolerance to the use of chemicals is likely to be intermediate in the absence of significant study on the specific types of aquaculture chemicals used and recoverability is intermediate. Sensitivity is therefore moderate.

Pathogen transmission: not relevant.

Inter-breeding with wild organisms: not relevant.

Introduction of alien species: not relevant.

Indirect ecosystem impacts: not relevant.

6.11 OTTERS

6.11.1 Background

Species Description: the otter (*Lutra lutra*) is relatively common along the north west Scotland coast, the Hebrides, Orkney and Shetland, but has suffered a dramatic decline in population size elsewhere in Europe (Fish Vet Group, 2004). Otters are shy, semi-aquatic, mostly nocturnal creatures (although they can be diurnal where they suffer little disturbance) and are, therefore, very rarely observed. They are found in almost all wetland habitats including lochs, rivers, burns, ditches, reedbeds, marshes, estuaries and the coast. Otters forage in water depths of 0 to 10 m and primarily prey on inshore benthic fish species, though crustacean also form an important part of their diet.

Species Importance: the otter is listed on Appendix I of CITES, Appendix II of the Bern Convention and Annexes II & IV of the Habitats Directive. It is also protected under Schedule 5 of the Wildlife and Countryside Act 1981 and Schedule 2 of the Conservation (Natural Habitats etc.) Regulations, 1994.

This protection means that it is an offence to deliberately:

- Kill or injure otters;
- Capture or keep otters ;
- Destroy, damage or obstruct their den;
- Disturb them while in the den;
- Sell or advertise for sale, otters and anything derived from them; and
- Import or export otters, whether dead or alive.

6.11.2 Sensitivity Assessment

Sedimentation: potential impacts from sedimentation could occur indirectly to otters through a reduction in foraging area as a result of smothering of benthic species and subsequent changes in food availability, particularly to inshore benthic fish or crustaceans (Fish Vet Group, 2004). Although otters have continued to occur in areas where there has been a long history of salmon farming, it has been suggested that salmon farms have not had a significant adverse impact on prey availability to otters (Fish Vet Group, 2004). However, of greater importance is the impact of the use of medicines and chemicals that could impact otter prey species, which is discussed further below under the section on 'Chemical Use'. Tolerance is likely to be high and recoverability is high. Sensitivity to indirect impacts as a result of sedimentation is therefore likely to be low.

Change in bio-geochemistry: potential impacts from changes in bio-geochemistry could occur indirectly to otters through indirect impacts from consumption of shellfish that have become infected with Diarrhetic Shellfish Poisoning (DSP) or Paralytic Shellfish Poisoning (PSP) as a result of nutrient enrichment causing toxic algal blooms. However, impacts to otter populations from aquaculture activities do not document this as a significant impact. It is therefore unlikely that otters will significantly impacted by changes in bio-geochemistry. There is therefore no sensitivity with respect to changes in bio-geochemistry.

Change in coastal processes: not relevant.

Infrastructure impacts: habitat loss and disturbance are a major factor in the otter's decline in numbers. Generally, it has been found that otters will tolerate the water-based and land-based activities associated with fish farming as long as it does not disturb their holts (Marine Harvest, 2003, Fish Vet Group, 2004). However, where infrastructure development causes a reduction in foraging area or prey populations (particularly inshore benthic fish or crustaceans), otter populations are highly susceptible to changes in food availability. Studies carried out in Scotland have shown that coastal otters focus the large majority of their foraging in water depths of less than 5 m and fish farm sites are generally located in depths of greater than 10 m (Fish Vet Group, 2004). Tolerance is intermediate and recoverability is high. Sensitivity to the presence of aquaculture structures impacts is therefore low.

Visual land and seascape modification: not relevant.

Disturbance: otters have been found to become rapidly habituated to predictable and/or frequently encountered noises or activities (Fish Vet Group, 2004). Temporary avoidance may occur in response to the close proximity of small boats/people; however, it is unlikely that any long-term impact on otter individuals or populations will occur. Tolerance is intermediate and recoverability is high. Sensitivity to noise impacts is therefore low.

Predator control: levels of predation by otters in Scotland appear low (Heffernan, 1999). Scaring devices (usually acoustic) are also used against otter predation. However, it has been noted that otters are able to become rapidly habituated to predictable or frequently encountered noise sources. Otters will react by temporarily avoiding the noise source, though there is no evidence to suggest that there are long-term impacts on individuals or populations (Fish Vet Group, 2004). Anti-predator nets and perimeter fences will also give rise to otter mortalities in the event that otters become entangled in the nets. Tolerance is intermediate and recoverability is high. Sensitivity to predator control measures is therefore low.

Chemical use: the impacts of chemical pollution on otters could range from direct physical poisoning to degradation of important habitats. However, there is little literature that discusses the impacts from specific chemicals used in aquaculture and their potential impacts to otters. The potential for impacts from chemicals during aquaculture operations would be from accidental pollution events, such as from diesel spillages during barge fuelling. Tolerance is intermediate and recoverability is high. Sensitivity to noise impacts is therefore low.

Pathogen transmission: not relevant.

Inter-breeding with wild organisms: not relevant.

Introduction of alien species: not relevant.

Indirect ecosystem impacts: not relevant.

6.12 FISH

6.12.1 Background

Species Description: the main species involved in mariculture activities include finfish in net pens and cages, finfish in ponds, bivalves, shrimp/prawn and aquatic plants. The main European aquaculture species is the Atlantic salmon, although there are farms for rainbow trout, halibut, turbot and sea trout.

The main cultivated shellfish species are mussels, oysters and king and queen scallops. A number of different methods of shellfish cultivation are used in EU waters. Mussels are grown on weighted ropes suspended either from buoyed lines (the long line system) or wooden rafts. Oysters are grown either in trestles placed in the intertidal zone, in stacks of trays located just below the low water mark, or in net bags suspended from rafts. Scallops may be grown on the sea bed, or in nets hung from buoyed lines or rafts, or suspended on ropes by threading a tag through a hole drilled in one of the lobes of the shell ("ear-hanging") (http://www.scotland.gov.uk/library2/doc06/mff-25.htm).

Species Importance: at the European level, Atlantic salmon (*Salmo salar*) in freshwater has been named as a species of community interest under Annex II and V of the EC Habitats Directive. In addition, wild salmonids act as hosts for the young larval stages of the freshwater pearl mussel (also protected under Annex II of the Habitats Directive). In areas where freshwater pearl mussels are found, any activities which threaten wild salmon and sea trout populations may therefore also pose a threat to pearl mussel populations.

6.12.2 Sensitivity Assessment

Sedimentation: potential impacts as a result of sedimentation have the potential to result in the indirect effect in the burial of food sources for fish species. The extent and severity of impact being most pronounced at low energy locations where water exchange and/or wave action is limited. Modification of the substrate composition by smothering will be disadvantageous to the settling of most invertebrate larvae. There may therefore be a temporary reduction of the primary food source of some fish, which may result in either a decrease in the fish growth rate or fish species may leave the affected area to feed in areas unaffected by sedimentation. Tolerance of sedimentation impacts indirectly through smothering of fish prey items is therefore intermediate and recoverability is high largely because fish are mobile and able to move out of the affected area. Sensitivity is therefore low.

Change in bio-geochemistry: sustained reduction of dissolved oxygen can lead to hypoxic, (reduced dissolved oxygen), and anoxic, (extremely low or no dissolved oxygen), conditions. This situation can become markedly worse during summer months, where water becomes warmer and it can progressively hold less oxygen. Crustacea and fish are identified as the most sensitive organisms to reduced dissolved oxygen (DO) levels with the early life stages of fish and migratory salmonids as particularly sensitive. For estuarine fish, a minimum DO requirement of 3 to 5 mg l^{-1} has been suggested (Stiff *et al.*, 1992). Higher values may be required where fish have to traverse distances of more than 10 km, or where high quality migratory fisheries are to be maintained. Reduced DO levels have been reported to have contributed significantly to the elimination of the fish populations from the Thames estuary and its recovery has resulted from strict management of water quality, including inputs of organic matter and the artificial injection of oxygen into the water column during low DO events (http://www.ukmarinesac.org.uk/activities/water-quality/wq9_5.htm). Tolerance is therefore low and recoverability low, with overall sensitivity being high.

Change in coastal processes: not relevant.

Infrastructure impacts: fish tend to aggregate around objects placed in the sea; however, this attraction is poorly understood. It is thought that the objects provide shelter from currents and wave action, safety from predators and to some degree food resources associated with invertebrate colonisation of any structures and excess food associated with fish farms. However, there lies the some potential for fish to become caught in fish farm netting, thereby causing mortalities, though this is much lesser problem than for marine mammals and birds. Tolerance to infrastructure is therefore high and recoverability is high, with no sensitivity to the presence of infrastructure associated with aquaculture activities.

Visual land & seascape modification: not relevant.

Disturbance: it is likely that the immediate impact of noise and vibration during construction would induce some form of 'startle' responses in fish species with good hearing capabilities, which may be accompanied by short-term avoidance reactions and then potentially a general habituation to any continuous noise source during operation of the aquaculture site. This response has been documented for fish from impacts due to noise and vibration from 'starting up' wind farms (http://www.seascape-energy.co.uk/es_files/Vol2/Vol%202.5%20-

%20Biological.pdf). Tolerance to noise impacts is likely to be intermediate in the short-term and recoverability will be high in the long-term. Overall sensitivity will therefore be low.

Predator control: not relevant.

Chemical use: outbreak of disease is more common in farming operations than the wild as a result of higher levels of stress in fish, high stocking densities and establishment of conditions conducive to the incubation of disease organisms. Commonly used chemicals include antibiotics, pesticides, disinfectants, antifoulants and hormones. Most antibiotics applied to mariculture systems end up in the sediment, though some can accumulate in wild fish and shellfish. However, a review of antibiotic use in Norwegian aquaculture concluded that it was unlikely to pose significant environmental or other problems at the low levels used in developed countries (http://www.rcep.org.uk/fisheries/Chapter6.pdf). Further, the environmental risk of antibiotic compounds used by the aquaculture industry is considered to be very low, due to the development of vaccines.

Of the range of pesticides used for sea lice treatments, two compounds (cypermethrin and emamectin) are the most widely used in the UK and considered to present the greatest environmental risk. However, impacts are restricted to sediment associated organisms as cypermethrin binds strongly to organic particles and is rapidly absorbed by sediments. Emamectin is also only able to pose a hazard to benthic species, though the long-term effects of this chemical on the marine environment is not well understood (http://www.rcep.org.uk/fisheries/Chapter6.pdf). Hydrogen peroxide, which degrades rapidly to water and oxygen, is not considered to be a hazard to marine life, but limited in use due to its difficulty in handling and limited effectiveness (http://www.rcep.org.uk/fisheries/Chapter6.pdf). Impacts to fish species are therefore likely to be limited to uptake of contaminants by wild fish and shellfish associated with the sediment and potentially those feeding on organisms within the sediment. For example, one study has shown that shellfish in the vicinity of the farm are likely to accumulate large concentrations of Ivermectin, which is a highly persistent organophosphate (Heffernan, 1999).

Copper has replaced tributyl tin (TBT) treatment in anti-foulants due to the highly toxic nature of TBT. When such coatings are used on nets, copper can slowly leach out into the water and to accumulate in the sediment. High levels of copper and other heavy metals in seawater are toxic to marine organisms. However, the long-term ecological implications of high metal concentrations in fish farm sediment are largely unknown. Sediment biogeochemistry and physical characteristics influence the accumulation, availability and toxicity of sediment contaminants, such as trace metals, to benthic invertebrates. Even when metal concentrations in sediments substantially exceed background levels, metal bioavailability may be minimal and adverse impacts may not occur. Ultimately, there is little evidence to date that copper is transmitted through the food chain, as it is present in an organic form that is not directly toxic (http://www.rcep.org.uk/fisheries/Chapter6.pdf).

Tolerance of fish species to chemical use is considered to be intermediate and recoverability high. Overall sensitivity is considered to be low.

Pathogen transmission: potential impacts of farmed salmonids on wild salmonid stocks can also occur through the transmission of disease (bacterial or viral) from farmed stock to wild stock and from transmission of parasites, e.g. of the salmon louse, *Lepeophtheirus salmonis*, from farmed to wild stock (Fish Vet Group, 2004). Intensive farming has increased the impact of sea lice on wild salmon and it is now one of the biggest issues for salmon aquaculture, and more recently is growing in importance for brown trout (http://www.rcep.org.uk/fisheries/Chapter6.pdf). Salmon in long fjordic systems found in Norway, are most at risk where wild populations must pass several farms during their migration to the sea, thus increasing the risk of exposure to sea lice infestations from farmed fish (Scottish

Executive, 2002). Transfer of other parasites from farmed to wild fish may be less of a problem, for example the parasite, *Gyrodactylus salaris*, from Scandinavia would potentially significantly impact Scottish wild salmonid populations, however, introduction via farmed fish is not thought to be the only or greatest risk of introduction (Scottish Executive, 2002).

Other infections may result from organisms naturally present in wild fish or the disease may spread from an exotic pathogen. For example, in 1985, a virulent strain of the bacterium *Aeromonas salmonicida*, which causes the disease furunculosis, was brought from Scotland to Norway, spreading to salmon farms and into wild salmon, killing large numbers of fish (http://www.biodiv.org/doc/meetings/mar/temctre-01/official/temctre-01-02-en.pdf). There is further potential for other infectious diseases (e.g. Infectious Salmonid Anaemia (ISA) and Infectious Pancreatic Necrosis (IPN)) to be transferred from farmed to wild stocks, however, the actual level of risk has not been able to be quantified at this stage (Scottish Executive, 2002).

Tolerance of fish species to transmission of pathogens from farmed to wild fish is considered to be intermediate and recoverability low. Overall sensitivity is considered to be high.

Inter-breeding with wild organisms: the potential impacts of farmed salmonids on wild salmonid stocks may arise from escapes from salmonid farms, leading to the possible over-running of wild fish spawning by escaped, mature farmed fish and ultimately 'genetic pollution' as a result of inter-breeding of these escaped farmed salmon with wild salmon (Fish Vet Group, 2004). Inter-breeding between farmed and wild fish can result in lower wild stock fitness and fecundity and ultimately potentially threatening stock numbers. However, in order for escapes to lead to a catastrophic impact and potential extinction of wild stock species it must be appreciated that substantial and repeated escapes of mature farmed fish, which then succeed in entering the same river system as wild stocks, would be required to out-compete a significant proportion of wild fish breeding (Fish Vet Group, 2004). Generally, measures to reduce the number of escapees have largely relied on 'good practice', and though it has been difficult to directly establish the effectiveness of these measures, it has been found that the frequency of escaped fish in EU waters has decreased in recent years (Youngson *et al*., 2001).

Studies of inter-breeding of farmed fish with wild stocks across the EU have shown differing results. For example, in western and northern Scottish rivers offspring from these crosses have low viability and are sterile, indicating that they could possibly displace local populations or establish feral populations in a vacant environmental niche, but they will not contribute genetically to native stocks (Heffernan, 1999). Conversely, interbreeding between escaped farmed salmon and wild Atlantic salmon studied in a Northern Irish river showed that the genetic composition of the wild population had become more like that of the presumed escapees, although still statistically significantly different and that the wild population had been altered by the escapees spawning in the river (Heffernan, 1999).

Though a number of studies have shown that escaped farmed salmon can cause long-term genetic changes in natural populations, such as growth and sea age of maturity, reported declines in wild stocks are almost certainly due to a complex interaction of factors, which include over-fishing, habitat modification and climate change (Beveridge, 2001). However, a precautionary approach is advised with respect to inter-breeding and escapes from salmon farms may constitute a significantly large threat to wild populations due to the large scale of escapes that occur (Scottish Executive, 2002). Tolerance to inter-breeding of wild stock with farmed fish is therefore intermediate to high and recoverability is low. Sensitivity is therefore moderate to high.

Introduction of alien species: the introduction of alien species comprises the escape of farmed exotic species that result in negative environmental impacts such as through habitat damage or through increased competition and predation. The former is rare in occurrence, for example, the introduction of red-claw crayfish from the U.S. to irrigated agricultural areas in the Iberian Peninsula gave rise to huge impacts to lost rice production as well as impacts on wildlife. With regard to competition and predation, the introduction of top carnivores may cause significantly greater impacts than introduction of omnivores or herbivores, though competition of space and prey species may only occur in the short-term (Beveridge, 2001). Tolerance to the introduction of alien species is intermediate and recoverability will be high. Sensitivity will therefore be low.

Indirect ecosystem impacts: dredging during harvesting of cultured shellfish species can have an adverse indirect effect on fish species through the destruction of the amount of productive fish habitat, such as seagrass (*Zostera*) habitat. Seagrass provides both an important nursery habitat for fish as well as a food source for fish such as pollock and flounder which feed on sand shrimp and other small organisms associated with eelgrass beds (Heffernan, 1999). Tolerance to losses of prey species and nursery habitat will be low in areas of seagrass habitat and recoverability will be low. Sensitivity will therefore be high.

6.13 BIRDS

6.13.1 Background

Species Description: studies undertaken in Scotland estimate that between 60 and 90% of fish farms have bird related predation problems from species such as cormorants (*Phalacrocorax carbo*), herons (*Ardea cinerea*), shags (*P. aristotelis*) and gulls (*Larus* sp.), (Beveridge, 2001). Auks such as puffins, black guillemots, razorbills, divers (red-throated, blackthroated and great northern) and red breasted mergansers are other predators which may visit fish farms. These birds do not usually feed on caged stock but may be attracted by an increase in wild fish in the vicinity of the cages and so may become entangled in anti-predator nets (Heffernan, 1999).

Five species of gull may frequent fish farms; black-headed, common, herring and great black-backed gulls throughout the year and lesser black-backed gulls during the spring and summer. They generally feed on waste food, or unprotected food on fish farms. The arctic and common terns are both associated with feeding at fish farms, where they take small fish (less than 10 cm) which they take by plunge diving. Gannets rarely have been reported as behaving similarly (Heffernan, 1999).

Species Importance: the Arctic tern (*Sterna paradisaea*) and red-throated and black-throated divers (*Gavia stellata* and *G. arctica*) are listed under Annex I of the EC Birds Directive. The eider duck, the common, herring and lesser black-backed gulls, and the Atlantic puffin are listed as migratory species under the EC Birds Directive.

6.13.2 Sensitivity Assessment

Sedimentation: the harvesting of cultured shellfish species, such as mussels, oysters and scallops from the seabed is carried out by dredging. Dredging activities have been found to adversely affect predators of benthic species, through either physical removal or smothering, such as the burrowing sand eel *Ammodytes* sp., which is the staple diet of many sea birds such as arctic terns, kittiwakes, puffins, great skuas and red-throated divers (Heffernan, 1999). Therefore, dredging in an area where birds are dependent on benthic species that may be smothered or destroyed can have serious implications for bird populations in that area. Dredging activities further adversely affect bird populations such as overwintering waterfowl such as Brent geese and wigeon by removing/smothering seagrass beds which provide an important food source (Heffernan, 1999). Tolerance to impacts causing sedimentation from shellfish aquaculture harvesting is therefore low in areas where benthic food sources are susceptible to dredging impacts and recoverability is low. Sensitivity is therefore high.

In areas where fin fish are cultivated and dredging activities do therefore not take place, it is likely that the sensitivity will be lower, although some sedimentation and smothering of benthic prey will occur due to waste nutrients and faecal/excess feed pellets being deposited on the seabed. Sensitivity to these impacts is likely to be moderate.

Change in bio-geochemistry: the consequences for seabirds with regard to reduced or extremely low dissolved oxygen levels are likely to be significant as the supply of food organisms is affected. Tolerance is therefore low and recoverability low, with overall sensitivity being high. Adversely, a localised increase in nutrients and colonisation of structures for marine invertebrates will increase food availability for resident and opportunistic bird species. This will produce a positive benefit to bird populations. There is no sensitivity therefore to increases in nutrients in this instance.

Change in coastal processes: not relevant.

Infrastructure impacts: the main cause of physical disturbance to birds will be as a result of the service and maintenance of the aquaculture structures for the cultivation of the Pacific oyster (Heffernan, 1999). Disturbance from intertidal shellfish farming is mainly caused by the presence of tractors and groups of people working on the mudflats. Bird species vary greatly in their susceptibility to physical disturbance, which is likely to vary with age, season, weather, location and the degree of previous exposure. Where birds are disturbed when feeding, they are likely to move and feed elsewhere; however, if they are disturbed when roosting, they are more likely to desert an area (Heffernan, 1999).

Disturbance from intertidal shellfish culture affects few breeding birds, mainly impacting on wintering birds as intertidal flats are of major importance as a habitat for many winter bird species. Their susceptibility to disturbance is due to a number of factors, which include the condition of birds post-migration, limited suitable habitat, harsh weather and prey accessibility in winter (Heffernan, 1999). Disturbance will be limited to low spring tides (i.e. exposure of the area between MLWN and the MLWS) but will ultimately be site specific and depend on the species of bird affected (Heffernan, 1999). Tolerance of wintering birds to disturbance is therefore likely to be intermediate and recoverability low, with overall sensitivity being high.

Visual Land & seascape modification: not relevant.

Disturbance: acoustic scarers for birds mostly involve sudden loud noises; however it has been documented that birds often become habituated to these noise sources (http://www.rcep.org.uk/fisheries/Chapter6.pdf). Other forms of noise disturbance may include from increased boat activity in the vicinity of the farm, however, there is little evidence to show that this has significantly impacted bird populations. Tolerance to noise impacts is high and recoverability is high. Birds are therefore not sensitive to noise disturbance.

Predator control: diving ducks can dive to depths of up to 30 m and feed on marine invertebrates (e.g. mussels). Numbers of Eider duck are known to be increasing in areas associated with mariculture in northern Europe and have been found to alter their seasonal pattern of movements to taken advantage of farming practices due to farmed mussels being more preferable to a potential predator than wild ones (Beveridge, 2001). Methods employed to deter predation by birds range from the presence of dogs/scarecrows and falcons to the installation of scaring devices that utilise flashing lights or sounds e.g. recorded boat engines or loud bangs. The effectiveness varies and in same cases leads to eventual habituation by predators. Exclusion nets are generally very effective for fish cages when properly installed and maintained and have demonstrated that mortalities are reduce along with the incidence of wounding (Beveridge, 2001). Shooting has taken place, though it is generally illegal in EU countries. Further, it is noted that setting nets with the objective of entangling predators is illegal (Heffernan, 1999). Tolerance to the normal methods of predator control for birds is intermediate and recoverability is high. Sensitivity is therefore low.

Chemical use: pesticide residues and other toxic chemicals have been implicated in bird population crashes (http://www.snh.org.uk/pdfs/trends/seas/SeasAroundScotland.pdf), though it is unclear as to whether these chemicals are those specifically related to aquaculture activities. The organophosphate class of chemicals, such as Dichlorvos and trichlorphon used to control sea lice include nerve gases and many insecticides, which though not well studied in terms of impacts to the marine environment; the dichlorvos group are toxic to some crustaceans and molluscs and may bioaccumulate in birds feeding on these benthic species (http://www.biodiv.org/doc/meetings/mar/temctre-01/official/temctre-01-02-en.pdf). Tolerance of chemical use is intermediate through bioaccumulation and recoverability is also intermediate. Overall, sensitivity is therefore likely to be moderate.

Pathogen transmission: not relevant.

Inter-breeding with wild organisms: not relevant.

Introduction of alien species: not relevant.

Indirect ecosystem impacts: indirect impacts to bird populations have occurred as a result of the large-scale collection/harvesting of mussel seed for relaying and on-growing. For example, inter-tidal mussel beds in the Wadden Sea almost disappeared during the late 1980s due to a combination of collection for farms and low spat fall. This in turn had a negative impact on bird populations for which the mussels were a source of food and led to increased mortality in eider duck and reduced breeding success for oystercatchers (http://www.rcep.org.uk/fisheries/Chapter6.pdf). Tolerance for birds dependent on wild shellfish species which may be harvested for aquaculture is therefore low and recoverability is low. Overall, sensitivity is high.

Space occupation and the subsequent loss of habitat in intertidal areas where oysters are farm will also directly impact certain bird species. Wader species are most likely to be affected by loss of habitat as they feed and roost in areas suitable for shellfish farming and on the low shore to mid shore. Other species which may be impacted are the golden plover as well as some geese species (Heffernan, 1999). Tolerance for these sensitive bird species is therefore low and recoverability is low. Overall, sensitivity is high.

7 RISK IDENTIFICATION AND ECOSYSTEM VULNERABILITY

7.1 LINKING SYSTEM-SPECIFIC PRESSURES AND VULNERABLE ECOSYSTEMS

7.1.1 Methodology

Understanding the impacts and interactions between different aquaculture systems and sensitive habitats and species in their vicinity, is made complex by the degree of impact (i.e. magnitude, significance, duration and distribution) on natural environments associated with these. To facilitate understanding of this issue, a risk-based assessment framework has been developed building on the assessment of linkages (hereafter termed **Pressure level)** between key pressures and aquaculture systems in Section 5 and **Sensitivity** assessment of key habitats and species to aquaculture pressures developed in Section 6.

The methodology for carrying out this risk assessment of sensitive habitats and species to aquaculture developments uses a stepped approach, following a framework previously used and accepted on a recent EC Habitats Directive related project (Atkins, 2005).

- **Step 1: Initial screening** (Section 3.5) to determine if there is an impact pathway from aquaculture to habitats and species of conservation importance. The habitats assessed at this stage are drawn from Annex 1 of the EU Habitats Directive and which have also been crossed referenced to the EUNIS habitat classifications. Where the screening has identified a relationship, the habitat has been taken through to the sensitivity analysis stage. For the species, the main animal groups impacted upon from aquaculture activities have been identified for sensitivity analysis and are representative of species of Annex IV and Annex I of the EU Habitats and Birds Directives.
- **Step 2: Determine Pressure level (**linkage**)** between key pressures and aquaculture systems. This analysis (Section 5) is based on a literature review and characterisation of each of the key pressure categories to develop an understanding of the strength of their relationship to various aquaculture systems.
- **Step 3: Sensitivity analysis of key habitats and species** to different aquaculture pressures (Section 6). As discussed in the previous section, this analysis is based upon a large body of previous work, with the outputs from these studies providing the key sources of information for the sensitivity analysis.
- **Step 4: Determine Risk** of impact to key habitats and species based on the combined degree of the *Pressure level* of pressure categories with aquaculture system and the *Sensitivity* of key habitats and species to different aquaculture pressures as outlined in the table below where *Risk = Pressure level x Sensitivity*.

Table 31: Risk Identification Table

Sensitivity / Pressure	Habitat Sensitivity			
	HIGH	**MEDIUM**	**LOW**	**NEGLIGIBLE**
HIGH	High	High	Medium	Negligible
MEDIUM	High	Medium	Low	Negligible
LOW	Medium	Low	Low	Negligible
NEGLIGIBLE	Negligible	Negligible	Negligible	Negligible

High: the habitat or species is very adversely affected by an external factor arising from aquaculture activities and is expected to recover over a very long period of time, i.e. >10 or up to 25 years or not at all; **Moderate**: the habitat or species is adversely affected by an external factor arising from aquaculture activities but is expected to take more than 1 year or up to 10 years to recover; **Low**: the habitat or species is affected by an external factor arising from aquaculture activities and is expected to recover relatively quickly.; **Negligible:** no discernable affect from aquaculture can be detected upon the habitat or species.

7.1.2 Cage Culture

Sea cages are widely used for rearing pelagic and epi-pelagic finfish, such as salmon, trout, sea bass and sea bream, in coastal and open waters. Their popularity stems from the efficient utilisation of the water column in tidal or other current-driven sites that alleviates the use of dedicated water supply and drainage. However the openness of the system makes it vulnerable to external influences (i.e. pollution events or physical impact) as well as exposing the adjacent environment to the stock, husbandry by-products and farm inputs such as chemical treatments.

The table below shows the sensitivity of the different habitat, community and species groups to the different environmental pressures emanating from cage culture (see Section 5). These are discussed in more detail overleaf.

Table 32: Habitat Risk Matrix - Cage Culture

Pressure Category		System-related Pressure Level (see Table 14, p. 47)	Habitats, Communities and Species Sensitivity													
			Reefs: mussel beds	Reefs: polychaete	Sea grass beds	Sand/mudflats	Maerl beds	Kelps & seaweeds	Saltmarshes	Sand dunes	Shingle	Cetaceans	Pinnepeds	Otters	Fish	Birds
1. Sedimentation	*Smothering*	Medium														
	Turbidity															
2. Change in bio-geochemistry	*Dissolved O_2*	High														
	Nutrients			?												
3. Change in coastal processes		Negligible														
4. Infrastructure impacts		Negligible														
5. Visual land & seascape modification		Medium														
6. Disturbance		Medium														
7. Predator control		High														
8. Chemical use		High		?			?	?								
9. Pathogen transmission		Medium		?					?		?					
10. Inter-breeding with wild organisms		Medium														
11. Introduction of alien species		Medium														
12. Indirect pressures on the ecosystem																

Sensitivity Key

High **Moderate** **Low** **Negligible** **? Uncertain**

System-related Pressures: as a partially-open system, cage culture is considered to have medium to high levels of potential impact for most pressure categories. The significance of these pressures depends a great deal upon a number of siting and operational variables (see Section 7.2), thus making site selection in particular a critical factor in ensuring the acceptability of such systems in sensitive sites.

Probably the most important pressure is the *change in water column bio-geochemistry*, both in terms of altering local $d0_2$ levels as well as altering the nutrient balance of receiving waters, especially when flushing is limited (see Section 5.2 on page 54 for more details). Poorly managed systems can also produce high levels of *organic and inorganic sediments*, leading to local water column turbidity and more seriously the smothering of benthic habitats within the deposition zone. The improvement of feed digestibility, as well as systems to reduce food wastage, has reduced but not eliminated this problem. As these systems are vulnerable to both *avian and aquatic predators*, their control can also be a serious issue. Again the openness of cage systems can lead to the exchange of pathogens between wild and cultured organisms, and the vulnerability of net cages to damage makes the possibility of escape inevitable, leading to potential *inter-breeding with wild stocks* and the *introduction of exotic species* to the wild. Other medium-level pressures of cage culture include the *visual impact of cages* in wilderness areas as well as the *disturbance* from feeding, feed/stock transport, harvesting and maintenance operations.

Ecosystem Risk: cage systems will tend to impact sublittoral habitats that are within the deposition zone of sediments and – if the site is insufficiently flushed – through a change in the trophic status of the waterbody. A glance at the table on the previous page shows that mussel and / or polychaete reefs, seagrass beds, sand & mudflats, maerl beds and seaweed beds are all potentially impacted by sedimentation, changes in $d0_2$ and hyper-nutrification from poorly sited cage farms. Other potentially high risk impacts include chemical use, especially over sensitive mussel or barnacle communities, where their tolerance and recoverability is considered low (see Section 6.1.2). Similarly seagrass beds, such as *Zostera* spp and *Posidonia* spp. that may be associated with cage culture sites also have low tolerance and recoverability from chemical toxicity. The impact of chemicals used in aquaculture on other sensitive communities such as maerl beds and seaweed communities is less well known, so a precautionary approach is required to intensive cage farming use in their vicinity. Sea lice treatments in Scotland and Ireland have been implicated in eye damage to wild sea trout (*Salmo trutta*) stocks.

Predator control and to a lesser extent disturbance was also an important risk from cage culture. In northern areas of Europe, piscivorous birds such as cormorants and herons may be attracted to cages and can cause stock damage if top nets are not secured properly, and therefore may be persecuted by farmers. Aquatic mammals such as seals and in the Mediterranean, common dolphins, may predate on exposed live, moribund or freshly dead fish in cages, causing damage to the netting and again may be targeted. Disturbance impacts may be present, but are usually fairly low and transitory as the cages are usually in deeper water away from bird nesting of foraging areas.

One ecological issue particularly associated with cage culture is that of the interbreeding of escaped fish with native populations. This has become a particular issue with Atlantic salmon as this may lead to domestication and loss of fitness in river-specific sub-populations (see Section 5.10). This situation is less clear in the farming of Mediterranean species such as sea bass and sea bream, but given the centralisation of hatchery production this may emerge and a significant issue once further investigated.

Scalar Issues: many of the pressures on sensitive environments resulting from cage culture occur in zone A, that within a few hundred metres of the cages. Here occur the direct effects of sedimentation, disturbance associated with cage mooring and maintenance, and of chemicals and medicines associated with sinking particles. Some European countries forbid significant impact on benthic communities, others permit an allowable zone of effect. In either case it would seem prudent to avoid siting cage farms where their zone A overlaps with sensitive communities etc. Since the size of this zone is in most cases defined by sinking particles, its exact dimensions depend on physical conditions, and can be estimated using models such as DEPOMOD or MERAMOD.

Whereas zone A pressures are often obvious, those on zone B scales may be more subtle. Nutrients dispersed throughout zone B water bodies may stimulate increased biomass of phytoplankton to an extent that significantly decreases water transparency (with impacts on phytobenthos) or causes increased consumption of dissolved oxygen when the resulting organic matter sinks into deeper water under stratified conditions. Chemicals may also exceed long-term EQS. Appropriate zone B scale models can be used to estimate safe loadings in these cases, using EQSs that are appropriate to sensitive communities or species within these water bodies.

Total production of cage-farmed fish would have to be very high for their waste products to give rise to significant ecological pressure on zone C scales. It has been alleged, for example, that salmonid farming in North-West Scotland was releasing sufficient nutrients into the regional sea to increase the risk of harmful algal blooms, which in turn impacted on shellfisheries. Tett & Edwards (2002) concluded that such a link was unlikely at existing regional production levels of about 150 thousand tonnes per year. However, there must be an upper limit to sustainable regional production. Estimation of such a limit, using either a simple budgeting method or a complex ecosystem model, should take account of the other anthropogenic discharges of nutrients, BOD and toxic pollutants that occur on the regional scale.

7.1.3 Shellfish Rafts and Longlines

Mussel and other shellfish aquaculture in deeper waters through the use of suspended ropes and longlines from floating rafts has developed to take advantage of spat fall locations as well as areas of good water quality and food availability. This form of aquaculture has become a particular feature of the Galician coastline of Spain (see case study in Section 8.2), as well as south-west Ireland and some Scottish lochs.

Table 33: Habitat Risk Matrix - Shellfish Rafts and Longlines

Pressure Category		**System-related Pressure Level (see Table 14, p. 47)**	**Habitats, Communities and Species Sensitivity**													
			Reefs: mussel beds	**Reefs: polychaete**	**Sea grass beds**	**Sand/mudflats**	**Maerl beds**	**Kelps & seaweeds**	**Saltmarshes**	**Sand dunes**	**Shingle**	**Cetaceans**	**Pinnepeds**	**Otters**	**Fish**	**Birds**
1. Sedimentation	*Smothering*	Medium														
	Turbidity	Medium														
2. Change in bio-geochemistry	*Dissolved 0_2*	Medium														
	Nutrients	Medium		?												
3. Change in coastal processes		Negligible														
4. Infrastructure impacts		Negligible														
5. Visual land & seascape modification		Medium														
6. Disturbance		Medium														
7. Predator control		Low														
8. Chemical use		Negligible														
9. Pathogen transmission		Negligible														
10. Inter-breeding with wild organisms		Negligible														
11. Introduction of alien species		Low														
12. Indirect pressures on the ecosystem																

Sensitivity Key

High | **Moderate** | **Low** | **Negligible** | **? Uncertain**

System-related Pressures: shellfish raft systems have three areas of medium sensitivity (see Pressure /System Sensitivity column in the table on the previous page), these being sedimentation, visual land and seascape modification and disturbance. Sedimentation is possibly the most influential of these, in that the deposition of faeces and pseudofaeces beneath mussel farms effectively lead to organic enrichment and thus alter macrofaunal communities – possibly averaging around 345 kg m^{-2} $year^{-1}$ (Grenz, 1989). Raised water column turbidity is also possible, leading to reduced primary production and possibly impacts on sensitive pelagic fauna. The other two areas of particular sensitivity from suspended culture is the impact of the floating rafts on the seascape as well as disturbance. The former is dependent upon the perceived human sensitivity to the infrastructure, which will reflect the scale, setting and level of visitor use. Disturbance is also dependent upon the situation, but these facilities have less servicing than finfish cage culture. Finally, the suspended culture of exotic species may result in the establishment of these species in local waters, although the nature of such systems e.g. the use of local spat fall, usually means that this is unlikely.

Ecosystem Risk: like cage culture described earlier, suspended rope culture will impact sublittoral habitats within the deposition zone, rather than inter-tidal or supralittoral areas. In contrast to cage systems, these impacts are mainly limited to sedimentation impacts on wild mussel reef communities, as well as other sensitive sublittoral habitats such as polychaete reefs, seagrass beds, sandbanks, maerl beds and seaweed beds. With the exception of sand and mud banks, both tolerance and recoverability of these important habitats to sedimentation is low.

When combined in extensive arrays, suspended shellfish culture may have a discernable impact upon the water column in both terms of $d0_2$ levels as well as nutrients. For instance, it is estimated that mussel culture may extract around 10% of primary production from a given area (Figueiras *et al*, 2002) in the rías of Galicia. This may have beneficial results for oligotrophic communities such as sea grasses but might restrict food availability for other filter feeders such as polychaete worms and sand / mudflat communities.

Scalar Issues: suspended shellfish culture may have a significant effect on the *zone A* scale through the sedimentation of faeces and pseudofaeces, and so should not be sited where the scale overlaps with sensitive communities etc. As in the case of cage farms, the effected zone extends beyond the rafts and longlines to an extent that depends on physical conditions, but which should be susceptible to estimation by particle-tracking models. The *zone B* effects are mainly those of removal of phytoplankton or some components of phytoplankton; this effect can be estimated by simple models and compared with appropriate EQS in order to estimate a safe shellfish loading (i.e. one avoiding significant impacts on sensitive communities). It seems unlikely that this method of shellfish cultivation will cause a significant impact on *zone C* scales, since mussel production is limited by primary production on this scale (in contrast to limitation by exchange on scales A and B), and nutrients excreted by the shellfish will stimulate extra production that largely makes up for what has been lost.

7.1.4 Inter-tidal Shellfish Culture

Inter-tidal shellfish culture is practiced extensively in the Western part of Europe and is one of the older, more traditional forms of aquaculture in the EU. It takes place within the inter-tidal area, thus benefiting from relatively accessible land-based support as well as the dynamic physical environment of the land/water interface.

Table 34: Habitat Risk Matrix - Inter-tidal Shellfish Culture

Pressure Category		System-related Pressure Level (see Table 14, p. 47)	Habitats, Communities and Species Sensitivity													
			Reefs: mussel beds	Reefs: polychaete	Sea grass beds	Sand/mudflats	Maerl beds	Kelps & seaweeds	Saltmarshes	Sand dunes	Shingle	Cetaceans	Pinnepeds	Otters	Fish	Birds
1. Sedimentation	*Smothering*	Low														
	Turbidity	Low														
2. Change in bio-geochemistry	*Dissolved O_2*	Negligible														
	Nutrients	Negligible														
3. Change in coastal processes		Negligible														
4. Infrastructure impacts		Low														
5. Visual land & seascape modification		Negligible														
6. Disturbance		Medium														
7. Predator control		Medium														
8. Chemical use		Negligible														
9. Pathogen transmission		Low		?					?		?					
10. Inter-breeding with wild organisms		Negligible														
11. Introduction of alien species		Medium														
12. Indirect pressures on the ecosystem		Negligible														

Sensitivity Key

High **Moderate** **Low** **Negligible** **? Uncertain**

System-related Pressures: inter-tidal shellfish systems are generally fairly extensive, although they can be concentrated in extensive, shallow shelving estuaries. As such, the physical and bio-geochemical pressures exerted by these systems are fairly low, but their presence in important bird feeding and fish nursery areas and need for active management means that they may impact on the integrity of sensitive coastal sites. There is also the risk of introducing alien organisms, either directly through culturing exotic species or indirectly through the accidental, such as the introduction of the slipper limpet (*Crepidula fornicata*) in association with imported American oysters (*Crassostrea virginica).*

Ecosystem Risk: the smothering of nearby inter-tidal and sub-littoral habitats with faecal and pseudofaecal material, as well as other detritus generated by the culture process is the main concern, with reef, sea grass, sand flats and maerl bed areas all at risk. The introduction of alien species such as *Crepidula* is known to impact maerl beds, whilst the introduction of exotic kelps such as *Undaria pinnatifida* or *Macrocystis pyrifera* may result in competition with endemic seaweed or kelp communities.

The extensive use of trestles or racks may impact upon the hydrology and sediment transport processes of inter-tidal areas, with resultant impacts upon both inter-tidal and sub-littoral habitats. They may also have an unsightly appearance, although this depends upon the density and types of equipment used as well as their past historical use and their acceptability by human residents and visitors. Similarly, the relatively high level of maintenance required by inter-tidal facilities may lead to high levels of disturbance, especially in important bird foraging and over-wintering areas.

Scalar Issues: *Zone A* may be extensive in these cases, depending on the lateral extent of cultivation and the area between high and low tide levels. The subtidal extent of zone A needs investigation, especially in highly energetic waters in which faeces and pseudofaeces may be spread over some distance. *Zone B* and *zone C* effects will be the same as those for suspended cultivation of shellfish.

7.1.5 Bottom Shellfish Culture

An extensive form of shellfish culture is where juvenile animals are placed or 'relayed' on a suitable substrate for on-growing. The substrate selected will depend upon the shellfish species being used – mussels and oysters prefer a hard or firm substrate whilst infaunal species such as clams or scallops prefer a softer substrate into which they can burrow. Despite the low level of impact of bottom culture, this form of aquaculture is often practised in shallow coastal or estuarine areas where there are often conservation areas for their sand / mud flat or seagrass communities, and thus there may be conflicts over use and management of the area.

A habitat risk matrix for bottom shellfish culture is provide below and discussed further overleaf.

Table 35: Habitat Risk Matrix - Bottom Shellfish Culture

Pressure Category		System-related Pressure Level (see Table 14, p. 47)	Habitats, Communities and Species Sensitivity													
			Reefs: mussel beds	Reefs: polychaete	Sea grass beds	Sand/mudflats	Maerl beds	Kelps & seaweeds	Saltmarshes	Sand dunes	Shingle	Cetaceans	Pinnepeds	Otters	Fish	Birds
1. Sedimentation	*Smothering*	Low														
	Turbidity	Low														
2. Change in bio-geochemistry	*Dissolved 0_2*	Negligible														
	Nutrients	Negligible														
3. Change in coastal processes		Negligible														
4. Infrastructure impacts		Low														
5. Visual land & seascape modification		Negligible														
6. Disturbance		Low														
7. Predator control		Low														
8. Chemical use		Negligible														
9. Pathogen transmission		Low		?					?		?					
10. Inter-breeding with wild organisms		Negligible														
11. Introduction of alien species		Medium														
12. Indirect pressures on the ecosystem		Negligible														

Sensitivity Key

High | **Moderate** | **Low** | **Negligible** | **? Uncertain**

System-related Pressures: this form of aquaculture is essentially an extensive, low impact approach. The main pressures emanating from bottom culture is a degree of sedimentation from both animal excretion as well as the dredging process used for harvesting and a degree of physical disturbance. The only medium category of pressure exerted by bottom culture is the introduction of alien species, as fast growing non-endemic species (such as *Crassostrea gigas*) are often used rather than local shellfish.

Ecosystem Risk: sublittoral benthic habitats such as mussel and polychaete reefs, sea grass beds, sand/mud flats/banks, maerl banks and seaweed / kelp beds may be impacted by smothering from sediments generated from excretory products or following harvesting, especially if hydraulic or physical dredges are used. If smothering occurs periodically then the level of recoverability is usually reasonable, especially if beds are scoured by currents. The impact from increased turbidity is usually low, and may even be beneficial for wild mussel beds if a small degree of water column enrichment occurs. However continuous turbidity, which is unlikely from such culture techniques, may impair seagrass and seaweed growth. There is also the chance of pathogen transmission from cultured to wild mussel populations, and significant infestations may result in loss of a portion of the wild mussel population. However tolerance levels and recoverability are reasonable, and high pathogen loads from bottom culture are unlikely.

The introduction of alien species can be a particular issue with these extensive systems which, as stated earlier, often overlap with SAC designations for their sand or mudflat communities and other features. Therefore the use of alien species such as *C. gigas* can be a sensitive issue in these areas, even if the species is already established in the area. In addition, the non-intentional introduction of alien species such as *Crepidula* is known to impact maerl beds.

Scalar Issues: *Zone A* may be extensive in these cases, depending on the lateral extent of cultivation and the area between high and low tide levels. The subtidal extent of zone A needs investigation, especially in highly energetic waters in which faeces and pseudofaeces may be spread over some distance. *Zone B* and *zone C* effects will be the same as those for suspended cultivation of shellfish.

7.1.6 Land-based Tank Systems

Land-based tanks systems are an intensive solution to culturing high value fish. Most systems are closed in that the growing facilities are contained within a site that is separated from the external environment by physical filters and drains. Many such farms use recirculation systems and may even use artificial seawater, thus reducing the inflow and discharge of water to and from the farm.

A habitat sensitivity matrix for land-based tank systems is provided below and discussed further overleaf.

Table 36: Habitat Risk Matrix - Land-based Tank Systems

Pressure Category		**System-related Pressure Level (see Table 14, p. 47)**	**Habitats, Communities and Species Sensitivity**													
			Reefs: mussel beds	**Reefs: polychaete**	**Sea grass beds**	**Sand/mudflats**	**Maerl beds**	**Kelps & seaweeds**	**Saltmarshes**	**Sand dunes**	**Shingle**	**Cetaceans**	**Pinnepeds**	**Otters**	**Fish**	**Birds**
1. Sedimentation	*Smothering*	Negligible														
	Turbidity	Negligible														
2. Change in bio-geochemistry	*Dissolved O_2*	Low	Low	Moderate	Moderate	Moderate	Moderate	Moderate	Low						Low	Moderate
	Nutrients	Low	Low	?	Moderate	Moderate	Moderate	Moderate	Low							
3. Change in coastal processes		Negligible														
4. Infrastructure impacts		High							High	High	High			Moderate		High
5. Visual land & seascape modification		Medium				High		Low	Moderate	Moderate	Moderate					
6. Disturbance		Low				Moderate			Low	Low	Low	Low	Low	Low	Low	Low
7. Predator control		Low			Low	Low			Low	Low	Low			Low		Low
8. Chemical use		Medium	High	?	High	High	?	?	High	Low		Moderate	Moderate	Low	Low	Moderate
9. Pathogen transmission		Medium	Moderate	?					?		?				High	
10. Inter-breeding with wild organisms		Low													Moderate	
11. Introduction of alien species		Low			Moderate	Low	Moderate	Moderate							Low	
12. Indirect pressures on the ecosystem																

Sensitivity Key

High | Moderate | Low | Negligible | ? Uncertain

System-related Pressures: this system contrasts to open systems such as fish cages, in that the main pressures are infrastructure-related. Although usually compact in size, land-based farms are generally highly engineered with extensive landscaping for water supply, grow-out and water treatment facilities. However, they are placed in the supralittoral area and can often be sited away from nature conservation features. As such, physical habitat alteration as well as sea and landscape impacts can be minimized or mitigated altogether.

As intensive units, chemical usage and pathogen transmission potential may be high. However this can be highly variable – in practice, most intensive land-based farms are both well managed to reduced chemotherapeutant use as well as the pathogen load in production systems and outputs of these to the external environment can be managed through filtration and water treatment.

Ecosystem Risk: the habitat sensitivity matrix suggests that there maybe some impact on sublittoral habitats such as reefs and seagrass / seaweed beds from elevated nutrients and biological oxygen demand. However, as suggested above, this very much depends upon the level of waste water treatment conducted by the farm, which can be highly efficient. Furthermore as it is a pollution point source, it can be easily monitored and may well be subject to consent limits.

The habitat sensitivity matrix also indicates a high level of possible infrastructure impacts. As explained above, these would only impact supralittoral environments such as saltmarshes, sand dunes and shingle if the farm were to be built on these habitats. In practice this would be highly unusual, as most land-based farms would be built upon firmer ground further inland and planned to avoid any conflicts with nature conservation interests. However some infrastructure elements, such as intake pump stations or discharge canals might encroach into designated areas.

If land-based farms are placed adjacent to sensitive coastal areas, there may be some perceived conflict in terms of alteration to the local land and seascape. However the footprint is fairly small, usually low rise and relatively easy to mitigate through landscaping. Disturbance from these farms is also minimal, as many facilities are either indoors or confined to a small area. Predator control is also likely to be minimal and mostly passive in nature i.e. netting and screening.

Other potential issues picked up by the habitat sensitivity analysis is the possible impact of chemical usage on sublittoral habitats as well as key species groups. Whilst theoretically this might be high given the intensity of land-based aquaculture, in reality outputs into the external environment can usually be controlled through management of the water and effluent systems. The introduction of alien species is also picked up. Again, this is a potential impact as an increasing number of farms are using heated seawater to produce fast-growing exotic fish species such as barramundi (*Lates calcarifer*) – however it is relatively easy to ensure containment of these closed systems and escapes are unlikely. However such a outcome should be investigated in site-specific environmental impact assessments.

Scalar Issues: the scale issues here are those addressed by the UK Comprehensive Studies Task Team in respect of urban waste water discharges: *zone A* is that effected by sinking particulates and *zone B* by dissolved substances such as nutrients and toxic chemicals. Assuming that such point discharges are well controlled by normal regulatory procedures, the main precaution in relation to avoiding undesirable effects from sedimentation, biogeochemical changes and chemical release, will be to avoid zone A overlap with the sites of sensitive communities etc. Effects of warm water, or fresh water, may be evident in zone A, but should also be taken into account on the zone B scale, bearing in mind that freshwater discharges may augment stratification. *Zone C* considerations are those discussed in relation to cage farm culture - that is to say, discharges from land-based farms must be added to those from all other point sources in estimating or predicting zone C pressures.

7.1.7 Land-based Pond Systems

Land-based ponds have been used for many centuries for fish culture. More widely used in freshwater situations, their use in coastal areas has stemmed from an intensification of lagoon and saltmarsh aquaculture where low-lying areas can benefit from the periodic inundation with spring tides. More modern pond systems have been built above the spring high tide mark but must then rely upon pumped water. These systems tend to be shallow – 0.75 to 1.5 m pond depth, extensive and therefore fairly large in nature. Pond systems can be used for finfish (e.g. turbot, sea bass and sea bream, sea-grown rainbow trout), shrimp and shellfish.

Table 37: Habitat Risk Matrix - Land-based Pond Systems

Pressure Category		System-related Pressure Level (see Table 14, p. 47)	Habitats, Communities and Species Sensitivity													
			Reefs: mussel beds	Reefs: polychaete	Sea grass beds	Sand/mudflats	Maerl beds	Kelps & seaweeds	Saltmarshes	Sand dunes	Shingle	Cetaceans	Pinnepeds	Otters	Fish	Birds
1. Sedimentation	*Smothering*	Medium														
	Turbidity	Medium														
2. Change in bio-geochemistry	*Dissolved O_2*	Medium														
	Nutrients	Medium		?												
3. Change in coastal processes		Medium														
4. Infrastructure impacts		High														
5. Visual land & seascape modification		High														
6. Disturbance		High														
7. Predator control		Medium														
8. Chemical use		Medium		?			?	?								
9. Pathogen transmission		Medium		?												
10. Inter-breeding with wild organisms		Low														
11. Introduction of alien species		Low														
12. Indirect pressures on the ecosystem																

Sensitivity Key

High	Moderate	Low	Negligible	? Uncertain

System-related Pressures: pond-based systems, especially those producing shrimp in tropical coasts, have received considerable criticism over the past two decades for a number of different reasons. These can be echoed in Europe, although tighter regulation here, especially with the increasingly restrictive measures on water abstraction and water quality protection, governed at the EU level by the Water Framework Directive (Directive 2000/60/EC).

Because pond systems tend to be semi-intensive in nature, they often require considerable areas of land to support the ponds and their related infrastructure (water supply and effluent canals). This land is usually situated either just above or within the spring tidal range, and is frequently made by draining low-lying, marshy land. Construction will usually involve a 'cut and fill' approach to building the ponds and surrounding dykes. This extensive reclamation in low-lying areas indicates why the construction of coastal pond farms may have high potential impacts on these areas with considerable alteration of the visual landscape. If the ponds have been reclaimed from lagoon areas, there is the potential for altering the local hydrological regime and thus impacting the functionality of the remaining parts of the lagoon.

The operational impacts of pond farms depend upon the species being cultured and the water supply regime employed. Whilst some species like turbot and trout require flow-through systems, others may require only the occasional topping up of ponds to compensate for seepage and evaporation – the latter then have a short-term pulse of detritus-laden effluent during harvest draw-down. There is the potential to ameliorate much of the impact of both flow-through and pulse discharges using settlement ponds and biofiltration.

The control of predators may well be a serious issue with pond farms, especially if the ponds are shallow enough to wade in, as they will attract attention forma wide number of avian and other predators. Chemical usage can be widespread, although can be controlled when conducted by appropriately skilled staff.

Ecosystem Risk: as mentioned above, the establishment of coastal pond farms can result in the alteration of low-lying land through pond and canal construction, reducing its ability to provide environmental services, especially in the case of saltmarsh areas, although supralittoral sand dunes and shingle can be affected. Likewise once construction is completed, even with landscaping coastal pond farms provide an artificial appearance at odds with surrounding land. Effluents from pond farms, unless reduced by settlement and biofiltration, can distribute large amounts of organic sediment around the discharge area, smothering biota and increasing the biological and chemical oxygen demand. Pond farms frequently fringe the edge of lagoon areas (e.g. the Mesolonghi and Amvrakikos lagoons in Greece) and their discharges – both individually and cumulatively, may impact seagrass beds as well as other sensitive habitats. In lagoon and semi-enclosed bays with limited flushing, pond farms might contribute to hypernutrification, with profound impacts on the water body's ecology and functionality.

Scalar Issues: *Zone A* is the pond, and *zone B* is the water body exchanging with the pond's contents. Both fish and shellfish ponds may enrich this water body with nutrients, or add to its BOD; filter-feeding shellfish may create a 'sink' for phytoplankton. The simple models discussed in relation to finfish cage, and suspended shellfish, farms can be used to estimate acceptable loadings on scale B, with EQS set appropriately for sensitive communities in these water bodies. *Zone C* issues are those mentioned in relation to land-based tank systems.

7.1.8 Lagoon Culture

Traditional coastal aquaculture originated from the Mediterranean, utilising the extensive coastal lagoons to capture migrating fish fry and grow them on for the table. Methods have grown more sophisticated over the past 50 years, leading to the gradual intensification of production as artificial feeding and water management technology have improved. Large brackish areas are enclosed to prevent the fish returning to the sea and complex permanent capture systems, fish barriers, were developed consisting of barriers in the channels communicating with the sea to catch the adults. Although some extensive systems depend upon natural fry within the system, most now rely on the stocking of juveniles from external sources.

Table 38: Habitat Risk Matrix - Lagoon Culture

Pressure Category		System-related Pressure Level (see Table 14, p. 47)	Habitats, Communities and Species Sensitivity													
			Reefs: mussel beds	Reefs: polychaete	Sea grass beds	Sand/mudflats	Maerl beds	Kelps & seaweeds	Saltmarshes	Sand dunes	Shingle	Cetaceans	Pinnepeds	Otters	Fish	Birds
1. Sedimentation	*Smothering*	Low	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Low		Low			Low	Low	Moderate
	Turbidity	Low	Low	Low	Low	Low	Low	Moderate								Low
2. Change in bio-geochemistry	*Dissolved O_2*	Low	Low	Moderate	Moderate	Moderate	Moderate	Moderate	Low						Low	Moderate
	Nutrients	Low	Low	?	Moderate	Moderate	Moderate	Moderate	Low							
3. Change in coastal processes		Medium	Moderate	Low		Low	Moderate		Low	Moderate						
4. Infrastructure impacts		Low	Moderate	Moderate	Moderate	Moderate	Moderate	Low	Low	Low	Low			Low		Moderate
5. Visual land & seascape modification		Negligible														
6. Disturbance		Medium				High		Low	Moderate	Moderate	Moderate					
7. Predator control		Medium				High			Moderate	Moderate	Moderate	Moderate	Moderate	Low	Low	Low
8. Chemical use		Negligible														
9. Pathogen transmission		Low	Low	?					?		?				Moderate	
10. Inter-breeding with wild organisms		Negligible														
11. Introduction of alien species		Medium			High	Low	High	High							Low	
12. Indirect pressures on the ecosystem																

Sensitivity Key

High	Moderate	Low	Negligible	? Uncertain

System-related Pressures: the risk from extensive lagoon culture scores low on most of the system-related pressures (see table on previous page), although may impact over three different areas. The first of these is the possible change in coastal processes – lagoon aquaculture may compartmentalise lagoon areas, adding water control devices that operate over different tidal cycles. These will inevitably impact the water circulation in the lagoon areas and most likely, when in combination with artificial stocking of aquaculture species, lead to a decline in biodiversity.

The second pressure emanating from lagoon systems is the impact on local wildlife and bird populations through a combination of operational disturbance as well as targeted predator control. Adjacent lagoonal areas, especially if they contain extensive intertidal mud and sand flats, may be subject to increased noise, boat and pedestrian activities. This is unlikely to be on a par with more intensive forms of aquaculture, but may be situated in the middle of a highly sensitive area, especially if traditional aquaculture rights are being challenged with more recent nature conservation designation.

The third pressure may result from the use of alien or locally-absent species. Lagoon systems are essentially open, with only a low degree of containment, and thus escapes will be inevitable. Some alien species, such as the Manila clam (*Ruditapes philippinarum*), are already used extensively in lagoon aquaculture and have become established in the local environment, with as yet largely unassessed consequences.

Ecosystem Risk: the main ecosystems being impacted by lagoon farming are those typical of lagoon areas – sand and mud flats, seagrass beds and kelps and seaweeds. Other areas – polychaete and mussel reefs and maerl beds may also be potentially impacted if found within or adjacent to lagoonal areas. Sand and mudflats will be subject to smothering from sediments emanating from the farm, and more profoundly by any change in the trophic status of the water body due to hypernutrification and organic deposition. They are important feeding habitats for avian waders and support considerable invertebrate infaunal communities. These may also be impacted by any significant change in overall productivity resulting from the introduction and husbandry of monoculture or restricted polyculture. In addition, if these cultured organisms include alien species, there maybe wider biodiversity impacts and disruption to endemic communities. Sea grass communities may be impacted by increased water turbidity, either due to the low levels of siltation but more likely from harvesting activities that involved raking or hydraulic-assisted extraction of clams. Seagrass communities may also be subject to wholesale removal during harvesting and have low levels of recoverability from rhizome displacement.

Other habitats are less likely to be impacted by lagoon aquaculture unless they are present or within the influence of lagoon systems, in which they may be impacted by increased sediment levels and a possibly altered hydrological regime as a result of lagoon compartmentalisation. As such systems tend to be extensive, the spatial impact zone (see below) is likely to be relatively small. However, should alien organisms or pathogens be introduced through the farming system then the effects could be more widespread.

Scalar Issues: A farmed lagoon can be seen as either a large *zone A* or else a strongly-managed water body on *scale B*. If it is a heterogeneous mixture of farms and sensitive communities on the sea-bed, then it is best seen as a zone B scale water body containing one or more zone As associated with fish farming, and considered according to culture type. If the lagoon is seen as a large and homogenous zone A, then consideration must also be given to the channel(s) through which it exchanges with the sea - these may need to be treated as point-source discharges with their own zone As. The adjacent part of the sea can then be considered as a zone B, with pressures and impacts estimated by simple models as already discussed, in turn exchanging with the large *zone C* scale - to which the lagoon is one of perhaps many contributors of chemical and biogeochemical change.

7.2 KEY PRODUCTION AND ENVIRONMENTAL VARIABLES DETERMINING ECOLOGICAL VULNERABILITY

The actual impact of aquaculture on a sensitive environment will depend upon both (i) the *scale and intensity of the activity* and (ii) the *resilience of the receiving environment.* It is essential to examine these, as they are key to determining:

- **Thresholds** for aquaculture development that might have significant effects on native species and other ecological impacts (see Section 7.3); and
- **Mitigation approaches** for incorporation into planning, design and operation of aquaculture in sensitive environments (see Section 7.4).

7.2.1 Scale and Intensity of Aquaculture Activities – 'Production Variables'

The previous section highlighted the linkage between the *nature and characteristics of an aquaculture activity* and the *level of the different pressures* (in terms of its magnitude, duration and distribution) emanating from the system. The significance of this pressure is considered separately with the environmental variables.

The key variables are summarised in the following table and discussed below.

Table 39: Summary of the Key Production Variables in Aquaculture

Trophic State of Production System

- Use of artificial feeds, natural productivity or a combination;
- Use of polyculture to improve trophic utilisation and reduce waste

Culture System Design

- Level of containment e.g. system choice (open systems like cages or closed systems such as land-based tanks) and improved containment through screening, settlement ponds.
- Adequate specification of structures to endure extreme weather events

Culture Site Positioning

- Layout of site e.g. concentrating site in one area or dispersing to smaller production units.
- Position of containment structure to reduce the risk of collision.
- Distance from sensitive environmental features
- Location down-current of sensitive environmental features
- Adjustment of feeding and husbandry patterns to tidal or seasonal conditions to minimise outputs
- Coordination with other aquaculture installations to reduce the cumulative impacts

Intensity of Production

- Biomass held in total, stocking densities
- Feeding and fertilisation rates, feed types, nutrient availability and digestibility

Operational Management Capacity

- Overall farm management capacity, including operational and maintenance planning, supervision skills, policy setting (e.g. environmental management)
- Husbandry skills, including feeding, grading and handling, stock stress reduction and harvesting.

Culture Species Used

- Use of endemic species, preferably from a local strain.
- Use of sterile or monosex individuals

Resource Needs

- Level of water, feed and other natural inputs.

Trophic State of the Production System: different energy sources can be used to produce aquaculture biomass. Essentially two classes are available:

- *Autochthonous:* 'natural' trophic systems deriving energy from solar radiation or nutrients already available in natural ecosystems; and
- *Allochthonous:* 'artificial' systems that derive their energy from external inputs.

Coastal European aquaculture is dominated by monoculture practices. Whilst efficient when conducted on an intensive basis, it becomes less efficient when used in extensive situations that depend upon natural productivity. Production variables can therefore include the level of trophic utilisation, which can then be increased by employing more species that occupy different feeding niches and strategies. In turn, this will reduce the level of inputs required (e.g. fertilisers) and reduce waste [production. This approach is no restricted to extensive systems – more intensive farms can employ different species mixes to absorb nutrients and predate escapees in effluent channels.

Culture System Design: in some circumstances, aquaculture investors can consider different culture system options. The final choice will usually depend upon the aims of the investment, the budget available and the sites available. Once the system is finalised, there can be different design approaches which will have an influence on the pressures emanating from the farm. These include the inclusion of extra screening and the construction of settlement ponds for land-based farms to reduce escape rates as well as the emission of nutrients and suspended solids. The inclusion of effluent control mechanisms in open systems such as cages is more difficult, although it is possible to engineer containment facilities to withstand prevailing and extreme weather conditions and thus reduce the risk of containment failure. In addition, the automation of feeding can reduce wastage from unskilled hand feeding and spread feeding over longer periods of the day, especially during the main growing period of the summer months.

Culture Site Positioning: an equally important factor for determining the environmental pressures originating from an aquaculture activity is its siting. This includes the position of the site relative to the feature of conservation interest, whether the facility is concentrated in one position or dispersed around a number of sites and whether the facility is exposed to risk from natural elements (e.g. strong prevailing winds, wave action, etc) or conflict with other coastal users (e.g. navigation, fishing activities, recreational users).

Intensity of Production: production intensity is the standard approach to identifying the potential impact of aquaculture on its surrounding environment. For open systems, this is a reasonable indicator of potential impact, not withstanding the local assimilative capacity (i.e. 'environmental variables'). In terms of European aquaculture, the most obvious example is cage culture, where a farm sites biomass will be roughly indicative of the overall potential environmental pressure exerted by the farm. However for closed systems, the intensity of production is not necessarily an indicator of its potential impact on the environment - for instance, a highly intensive farm using recirculation may be environmentally benign due to the small footprint and its isolation from the external environment.

Table 40: Key Production Variables and their Determinants

Variable		Determinant							
		Project design		Site selection		Farm management		Waterbody management	
Trophic state of Production Systems		+++	Corporate objectives, investment capacity						
Culture System Design		++	Species, investment capacity	++	Available options				
Culture System Positioning		+	Investment capacity	+++	Water quality, depth, flushing, distance from conservation feature	++	Fallowing	+	Coordination with other farming units
Intensity of Production		+++	Target markets, economic objectives	++	Water availability, climate	+	Feed management regime, filter mgt, water mgt.		
Operational Management Capacity	Policy level	+	Integration of EIA, investor's wider environmental policy	+	Implementation of EIA recommendations	++	Development of environmental policy and practical guidelines	+	Coordination with other farming units
	Operation level					+++	Quality of training and supervision		
Culture species	Exoticness	+++	Target markets, viability of endemic species	++	Isolation from natural waterbodies	+	Containment management and husbandry	+	Monitoring
	Fecundity	+++	Target markets, technical capacity					+	Monitoring
	Parasite load			++	Water quality, flushing, lack of other stressors	++	Water management and husbandry	++	Reduce stressors
	Genetic fitness	+++	Commercial advantage of domesticated stocks	+	Isolation and distance from natural populations	++	Containment management and husbandry		
Resource needs	In situ	++	Culture system selection	+++	Natural productivity, water quality	+	Pond management, supplementary feed regime	+	Maintain natural hydrological regime
	Remote	++	Target markets and investment capacity		Road and sea communications		Buying practices and objectives		

Linkage key: +++ high; ++ medium; + low

Operational Management Capacity: an often under-estimated variable is the capacity of both farm management to impose an environmental approach to operation and maintenance as well as the capacity for staff to undertake their duties in a skilled and responsible manner. This capacity operates at two primary levels: (i) policy and management framework and (ii) operational husbandry level.

- Policy and management framework level: an adequate environmental policy and implementation framework is essential, especially in larger organisations with dispersed sites and operations. This will then dictate the actions that will be taken at operational level.
- Operational husbandry level: staff need to have adequate training in implementing environmental management systems. Poorly trained staff will increase the risk of containment failure and the accidental release of stock, poor feeding practices that reduce FCRs and result in uneaten feed, stressed stock with greater vulnerability to disease, etc.

Culture species used: even within similar culture systems, the ecological impact of an aquaculture unit will vary according to the ecology and behaviour of the stocked species, both within the farming system and, in the case of escape, in the wild. This may be compounded where polyculture is employed in order to fill vacant niches within a system. The key variables involved here include:

- *Exoticness:* whether the species is endemic in surrounding waters or is an exotic that may compete with other endemic species for niches. The impact of this variable will also depend upon the ecosystem health of the receiving environment.
- *Fecundity:* if a breeding population is established in the wild, the species fecundity will, amongst other factors, dictate the rate at which the wild population as a whole becomes established. Fecundity might be affected through the use of mono-species, triploid or sterile stocks.
- *Parasite load:* introduced species may carry exotic parasites or pathogens. An example is the crayfish plague (a virulent disease caused by the fungus *Aphanomyces astaci*) that was introduced and is spread by the most frequently farmed species, the North American signal crayfish *Pacifastacus leniusculus*. This has contributed to the decline of the native white clawed crayfish (*Austropotamobius pallipes*) in Northern Europe.
- *Genetic fitness*: a key issue in the escape of farmed fish is the erosion of the genetic fitness of wild fish populations through inter-breeding with domesticated animals. Studies in Ireland have shown that farmed Atlantic salmon are only 1-2% as fit as wild fish (from egg to egg) and that wild stock transplanted from a neighbouring river system only 20% as fit as native stock (McGinnity *et al*, 2003). Therefore the degree of fitness of farmed fish relative to wild stocks is an important consideration. This will be particularly so if the farms are located in or adjacent to conservation areas where important stocks of wild, endemic species might be affected.

Resource input requirements: different forms aquaculture have varying demands for resources. These demands might be considered as both *in situ* and *remote* and these are briefly considered in terms of their impact on 'sensitive' environments:

- *In situ resource demands: in situ* demands are for resources only available from the immediate environment. This includes water, naturally available nutrients and prey items and dissolved oxygen. In addition, extensive forms of aquaculture may require the harvesting of juveniles for stocking into the 'controlled' production area. The use of these *in situ* resources can be influenced primarily by good site selection, facility design and management.

- *Remote resource demand:* some resources might be imported into the site, yet still have some impact on external 'sensitive' environments. The most obvious is fish feeds, where the protein contents of feeds is from 'feed fish' stocks, such as capelin, blue whiting, anchovy and sardine. If such feed fish are sourced from sensitive environments, then this should be considered in any assessment. A second external resource may be juveniles, usually from remote hatcheries or, more rarely in Europe, from capture fisheries. An example of the latter might be tuna juveniles for cage culture in the Mediterranean.

7.2.2 Resilience of the Receiving Environment – 'Environmental Variables'

The production variables described above will determine the magnitude, duration and distribution of the different pressures emanating from an aquaculture system. However, only with an understanding of local environmental conditions will it be possible to assess the actual impact and significance of these pressures on sensitive environments.

The resilience of the receiving environment will therefore depend upon a number of 'environmental variables' – an understanding of these is essential in order to propose site selection and environmental impact mitigation approaches. The main environmental variables are as follows:

- **Flushing:** residual or tidal currents, or flushing or exchange or dispersion rates as appropriate.
- **Water turbidity:** optical depth of the surface layer or water column, the product of layer or column depth and the submarine light attenuation coefficient.
- **Nutrient status:** the nutrient status (under reference conditions) of receiving waters and their response to additional nutrient input.
- **Water temperature:** affects metabolism of poikilotherms and the capacity of water to hold dissolved oxygen.
- **Wind speed:** increases levels of aeration but high wind speeds may damage gages and compromise stock containment.
- **Distance from sensitive habitat:** attenuation of impact and less likely to experience Zone A impacts
- **Assimilative capacity:** ability to absorb wastes without damage to ecosystem functioning.
- **Carrying capacity:** ability of a given environment to provide food for populations of organism dependent upon local production.
- **Ecosystem health:** a socio-ecological unit that is "stable and sustainable", maintaining its organization and autonomy over time and its resilience to stress, while capable of remaining economically viable and able to sustain human communities (Costanza, 1992).

The table overleaf examines these variables further, investigating the significance of high values in the pre-aquaculture state, the relevance of the variable to sensitive environments, regulatory and site management concerns.

Table 41: Detailed Evaluation of Environmental Variables

Variable	Significance of high values at site prior to aquaculture	Relevance of variable to sensitive habitats	Regulatory concerns (should be to..)	Site management concerns (should be to ...)
Flushing - residual or tidal currents, or flushing or exchange or dispersion rates as appropriate	Flushing remove wastes and resupplies oxygen and food, currents and turbulence keep particles in suspension	All communities in vicinity of farm are more at risk in regions of low flushing and currents; *basin deep water* in fjords, and *seasonal deep water* below thermocline, are regions where organic matter inputs may cause oxygen depletion, with harm to deep-water and benthic communities	Avoid consenting (intensive) farms in regions of low flushing, or impose stringent conditions and monitoring requirements here.	Be aware of periods/seasons when flushing particularly low and manage farm to avoid large waste inputs at this time; ensure that consented AZE is not exceeded
Optical depth of the surface layer or water column, the product of layer or column depth and the submarine light attenuation coefficient	Less light reaches the seabed and hence less probability of seagrass or seaweed growth, and less light in the surface layer so less risk of eutrophication	If seagrass or seaweed communities are natural biotopes (?) Then they are placed at risk by any increase in the optical depth; optically shallow waters are more likely to show a strong response to nutrient enrichment	Consent finfish farm loading in zones B and C so as not to cause more than 10% (?) Decrease in optical thickness in regions containing sensitive phytobenthic communities	
Nutrient status (under reference conditions)	Potentially eutrophic waters (if light and flushing permit); local ecosystems likely to be adapted to consume, efficiently, high levels of production	Oligotrophic (low-nutrient) waters likely to show strong response to nutrient enrichment; pulsed nutrient input is to be avoided, because it can cause blooms which grazers are unable to control	Consent finfish farm loading in zones B and C so as not breach indicative thresholds in Table 42. In regions containing sensitive communities/habitats	Manage nutrient release from farm so that it is least during seasons when the relevant ecosystems are most sensitive
Temperature	High metabolic rates of poikilotherms, and reduced capacity of water to hold oxygen	Any community that is sensitive to oxygen deprivation will be at greater risk at high temperatures	Take a more stringent view of loading in warm waters	Minimize waste releases when sea temperatures greatest
Wind speed	Better reaeration, greater depth of surface layer and stronger surface currents, but more risk of damage to cages		Seek to encourage farm sitings in more open conditions, taking account of fish release problems that may result from cage damage	Minimize waste releases during periods of unusually low wind speed

Variable	Significance of high values at site prior to aquaculture	Relevance of variable to sensitive habitats	Regulatory concerns (should be to..)	Site management concerns (should be to ...)
Distance from sensitive habitat		Distant sensitive habitats less likely to experience zone A impacts	Do not consent to farms which would contact sensitive habitats with their AZE	Ensure AZE remains within consented limits; understand and avoid particular local conditions in which wastes might be carried directly to conservation features
Assimilative capacity	Good capacity to absorb wastes from mariculture and other sources, without damage to sustainable ecosystem functioning	Sensitive habitats less at risk if in ecosystems of good assimilative capacity	Estimate assimilative capacity for each pollutant in zone B or C waters and allocate this fairly and transparently to users including aquaculture	
Carrying capacity	Good capacity to provide food for populations of organisms dependent on local production	Sensitive communities of filter feeders less at risk from competition by shellfish farms in ecosystems of good carrying capacity	Estimate phytoplankton food supply capacity for zone B and C and allocate this fairly and transparently to users including shellfish aquaculture	
Ecosystem health	Infers that the ecosystem shows no sign of stress prior to aquaculture, has remained stable over time and is resilient to stress.	Most healthy ecosystems are resilient to change, but if this health is compromised by some other influence e.g. pollution or over-harvesting, then it becomes more susceptible to additional stressors. Key stressors might include changes in nutrient status and bio-geochemistry as well as the introduction of alien organisms.	Assess ecosystem health indicators over time to ensure that naturalness and stability are retained.	Conduct environmental monitoring (physicochemical, biodiversity, etc) at different distances from the site.

7.3 THRESHOLDS FOR SUSTAINABLE DEVELOPMENT

For planning and operational purposes, it is useful to have thresholds for the different aquaculture-generated pressures that indicate the point beyond which small changes could potentially lead to long-term or irreversible effects (for example, endangered species becoming extinct). Without these, it is impossible to set limits within which aquaculture can operate in compliance with the biological, assimilative and visual carrying capacity of the local environment.

The setting of such thresholds for aquaculture is becoming increasingly common, although tends to be restricted to the assimilative capacity of the receiving water body, especially for cage farming – for instance the Strategic Framework for Scottish Aquaculture (Scottish Executive, 2003) sees the setting of environmental thresholds for assimilative capacity as key to setting biomass limits for cage farming sites. A submission to the Scottish Parliament (Nautilus, 2002a) also stated that "agreed warning action threshold levels for environmental indicators, and clear response procedures should be established" for the Scottish fish farming industry and goes on to suggest that "Any new strategy must start from clear and broadly agreed environmental objectives, with associated indicators and standards, relating to all the major environmental issues associated with aquaculture development. These objectives, standards and indicators should be developed, and broadly agreed between major stakeholder representatives, at both national and local level, taking full account of national, EU and international obligations".

The following section provides the basis for threshold values for the main environmental pressures associated with aquaculture development. Where possible, these are taken from existing EU or Member State standards or have been developed from existing literature on aquaculture or related industries.

Box 3: Example of environmental quality standards for sensitive habitats

Seagrass: No increase in mean seasonal levels of suspended solids; light levels at 2m depth should not normally fall below 10% of surface incident light; total Kjeldahl N not to exceed 140 μg/L; mean total N not to exceed 500 μg/L.

Corals: Deviation from mean ambient nitrogen concentrations should not exceed 5%; deviation from mean ambient phosphorus concentrations should not exceed 5%; no increase in mean ambient levels of suspended solids; changes in salinity levels from seasonal ambient state not to exceed 5 ppt.

Sandflats: No change in mean seasonal sand transport to exceed 10%; changes in salinity levels from seasonal ambient not to exceed 5 ppt; mean levels of organic carbon not to increase above ambient levels by more than 5%.

Based on the 'Draft Planning Guidelines - Protecting the Values of Coastal Ecosystems' prepared for the Queensland Department of Environment.

Table 42: Aquaculture Pressure Thresholds

Pressure		Thresholds / Reference Limits	Scale	Sensitive Habitats / Species *	Means of verification	Unit of Measure	Source	Comments
Sedimentation		AZE (see comments) that approaches conservation feature.	A	MBC, PWR, SG, SB, MB, KS, B	Model, direct measurement	Infaunal Trophic Index (ITI) (g solids / m2 / year)	SEPA 2004	AZE - Allowable Zone Of Effect, a small area beneath fish cages in which regulators allow some deterioration of conditions ITI, AMBI, RPD apply only in soft sediments
		Measurable increase in observed or simulated rate of sedimentation to benthos, or measurable change in ITI/AMBI, or depth of RPD, resulting directly or indirectly from mariculture	B					
Change in Bio-Geochemistry	*Oxygen concentration*	Oxygen concentration, decreased as a direct result of BOD addition or an indirect effect of nutrient enrichment, falls below region-specific levels, ranging from 4 to 6 mg oxygen per litre	A, B, C	MBC, PWR, SG, SB, MB, KS, F	Direct measurement	Oxygen concentration in water (mg oxygen per litre)		Painting et al. (2005). Special conditions apply to fjordic basin deep water
	Nutrient enrichment of water column	Increase over (seasonally-relevant) background of 50%	A, B, C	MBC, SG, SB, MB, KS	Direct measurement	Concentration of nutrients in water (uM)		indicates risk of eutrophication; nutrients are not directly harmful
	Change in water column chlorophyll concentration (mg/m^3)	Chlorophyll concentrations should not significantly deviate from reference condition envelope	A, B, C	MBC, SG, SB, MB, KS	Direct measurement	Concentration of chlorophyll in water (mg per m^3)		Painting et al. (2005). Tett et al. (submitted); chlorophyll is an indicator of eutrophication; increase points to greater risk of blooms and sedimentation, decrease to shortage of food for filter-feeders
	Decreasing water transparency	Any observed or predicted significant shallowing of the lower depth limit of seagrasses, seaweed or maerl	A, B, C	SG, SB, MB, KS	Direct measurement by Secchi disk	Water depth (m) down to which one can see the Secchi disk		Pergent-Martini et al. (2005)
Change in Coastal Processes		Minor alteration to sediment drift rates/current speeds/hydrodynamics (less than a 10% change) Change to the sediment budget / coastal hydrodynamics of the area sufficient to alter erosion / accretion patterns.	B, C	n/a	Measurement of current speeds and beach profiles from fixed benchmarks	Rate of accretion/erosion (cm/year)	No documented source linked specifically to aquacultural impact.	There is no detailed assessment of aquacultural development on coastal processes or landform change. See Strategic Env. Assessment & Coastal Erosion (Atkins 2003). europa.eu.int/comm/environment/iczm

Pressure	Thresholds / Reference Limits	Scale	Sensitive Habitats / Species *	Means of verification	Unit of Measure	Source	Comments
Infrastructure Impacts	Direct or indirect impact that changes the integrity of the site in relation to its designated features (species or habitats) Direct removal of any portion of a sensitive habitat during construction (building) or operation (dredging)	A	MBC, PWR, SG, SB, MB, B	Overlay geo-referenced development plans with Biotopes maps	Hectares of sensitive habitat removed		
Visual Land and Seascape Modification	Anything more than minor alterations to vista	B, C	n/a			Scottish Natural Heritage "Marine Aquaculture and Landscape: the siting and design of marine aquaculture developments in the landscape (2000)	
Disturbance (Noise)	Sound levels sufficient to cause permanent avoidance behaviour in protected species Sound levels over 10dB above background levels and sufficient to be a nuisance	A	n/a	Direct measure of noise levels	dB (10% above local L_{A90})	Environment Agency (2002)	
Predator Control	Permanent changes to life strategy and behaviour of protected predator species ADDs do not respect EU recommendations for frequency (10kHz) and source level (130-150 dB)	A, B	C	Direct measure of frequency and noise levels	kHz and dB	EU regulation No. 812/2004 (annex II)	
Chemical Use	Irreversible/sub-lethal changes in physiology and/or behaviour of protected species Exceeding of EQS for Aquatic Life for any substance	B, C	MBC, SG, SB, SM	Regular water and sediment sampling and analysis	[C] Concentration of chemicals in marine water and sediments (ppb, µg/l etc.)	Use of WFD and relative EEA guidelines (USEPA and NOAA guidelines are also available for water and sediments)	Bibliographic review Laboratory studies Field monitoring techniques Use of EQS is les species dependent and more measurable

Pressure	Thresholds / Reference Limits	Scale	Sensitive Habitats / Species *	Means of verification	Unit of Measure	Source	Comments
Pathogen Transmission	Disease or parasite transmitted to a detectable portion of population of protected species	B, C	F	Veterinary stats	No. of wild individuals found dead because of each disease / year		A "detectable portion" is considered as A significant fraction of populations under environmental variation.
Interbreeding with Wild Organisms	Proportion of farmed to wild fish in the population below (6%) Number of migrants exchanging genes < 1/generation to maintain genetic differences	C	F	Ratio can be calculated on the basis of escape statistics and estimates of wild populations	No. of escaped individuals / No. of individuals in the population in %	Norwegian Directorate of Nature Mngmnt 2004 Bartley 1999	Might be difficult to measure. Also ratio farmed/wild sufficient for introgression is unclear. Precautionary principle would leave it below 10%
Introduction of Alien Species	Any introduction of alien should be avoided where possible. If already locally present, then rigorous appropriate assessment will be necessary.	B, C	SG, MB, KS	n/a	n/a	ICES Code of Practice on the Introductions and Transfers of Marine Organisms (2004) and EC Council Regulation concerning use of alien and locally absent species in aquaculture (COM(2006) 154 final) provide similar risk assessment frameworks for the introduction of alien species which should be used as a reference in case an introduction is considered necessary.	
Indirect Ecosystem Impacts	Stocks of origin used as seed or transformed into feed show signs of overfishing	C	F, B	ICES, FAO or national statistics, *ad hoc* stock assessments	Yearly catch statistics (t) and long-term trends, fishing mortality rates	FAO 2004	

Key to sensitive habitats / species codes: MBC: Reefs: Mussel bed communities, PWR Reefs: Polychaete worm communities; SG Seagrass beds on sublittoral sediments; SB Sandbanks, mudflats & sandflats; MB Maerl beds; KS Kelp and seaweed communities; SmC Saltmarsh communities; SdC Sandune communities; ShC Shingle communities; C Cetaceans; Pinnipeds; Otters; F Fish; B Birds

7.4 PLANNING AND MITIGATION APPROACHES

The preceding sections illustrate the large number of production and environmental variables that will dictate both the pressures originating from the aquaculture activity / combination of activities, as well as the ultimate effect on sensitive areas. This infers two aspects:

- **Appropriate environmental planning** - at both at the cumulative waterbody level as well as the individual site-specific level - can ensure that sites are selected that have the capacity to assimilate waste production and to ensure that the conservation objectives of sensitive features are not compromised.
- **Site-specific EIA, environmental and operational management** can identify the pressures that might originate from aquaculture activities and develop proactive approaches to mitigate their output in terms of magnitude, duration and distribution.

7.4.1 Environmental Planning

Until recent years, the only form of environmental planning undertaken for aquaculture activities was a site-specific Environmental Impact Assessment (EIA). Whilst this mechanism has a number of values (see next section), as an EIA is normally undertaken at farm level it therefore cannot effectively address cumulative and wider environmental issues, such as nutrient enrichment and interactions with wild species. These need to be addressed at a higher strategic level. While this has been recognised for many years, and strategic, regional or sector level environmental assessment recommended, this is rarely undertaken in practice (Nautilus, 2002b).

A number of planning and mitigation approaches can be taken at sector or strategic levels. Hambrey *et al* (1999) suggest a range of seven instruments that can be used:

1. **Zoning and ICZM**: allows the pre-emptive avoidance or pre-empting of resource-use conflicts. Must be undertaken as part of a broader *integrated coastal zone management* (ICZM) approach to balance the strengths and weaknesses of alternate uses and their cumulative impact on the environment. The allocation of aquaculture zones can be reinforced by the setting of thresholds or environmental quality standards (EQS') to provide consistent criteria against which impacts can be judged.
2. **Management of environmental capacity**: essentially looks at the environmental capacity of a management zone. This zone might be a quantifiable coastal waterbody (i.e. a semi-enclosed bay, sea loch or ría or stretch of coastline. This approach is best suited for far field effects such as nutrient enrichment that can be modelled.

Box 4: Mitigation of nutrient enrichment through zoning

The ideal process

1. Define environmental quality standard for zone (e.g. acceptable N concentration);
2. Estimate assimilative/dispersive capacity of zone;
3. Estimate acceptable nutrient load on the zone (environmental capacity);
4. Estimate rate of nutrient production from aquaculture and alternative uses;
5. Develop incentives or regulations to prevent aquaculture and other activities exceeding the acceptable load. These might include:
   - allocation or sale of a portion of environmental capacity;
   - cessation of issue of permits once a critical total production threshold is reached;
   - cessation of issue of permits once an environmental quality standard is reached; and
   - pollution tax related to quantity of discharge

   The first of these has the advantage that the rules are clear from the outset, and it provides an incentive to minimize pollution while placing no restriction on production.

If the environmental capacity can be estimated or approximated, then various approaches are open including (i) allocating a proportion of that capacity to individual users or (ii) less desirably, defining the total acceptable aquaculture production (and inputs from other users) and halting the issue of permits when this production has been reached. If the environmental capacity cannot be assessed, then precautionary approaches such as the monitoring of water quality against agreed standards or a flat rate of pollution tax against a measured or estimate discharge. In Europe the Strategic Environmental Assessment (SEA) Directive (2001/42/EC) is widely accepted as a valuable means of integrating environmental information into decision-making and may provide a mechanism for zone-level environmental capacity assessment.

3. **Codes of conduct and practice**[19]: as recognised by the Terms of Reference for this study, codes are increasingly popular with international organisations, governments and the industry itself as their various benefits (see Box 5 below) are recognised.

Box 5: Benefits associated with the adoption of aquaculture Codes of Practice

- Enhanced public image and demonstrated industry responsibility;
- Greater common understanding and agreement on measures required for sustainable aquaculture;
- Clarification of roles and responsibilities;
- A framework and vehicle for awareness raising, information exchange, and training within and outwith the sector;
- A framework for the development of market led incentives (such as labelling and product certification) for improved management and sustainability;
- A "pilot run" for more formal financial incentives or regulations;
- A building block in the development of integrated coastal management; and
- A strengthened and informed negotiating position for the sector.

Adapted and developed from Barg, 1992

Examples range from general to specific and include the FAO *Code of Conduct for Responsible Fisheries*, and the associated *Technical Guidelines* which relate specifically to aquaculture; the *Global Aquaculture Alliance Codes of Practice*; and a variety of specific codes developed for particular countries, species or systems, such as the *Code of Good Practice for Scottish Finfish Aquaculture* (2006), the Federation of European Aquaculture Producers Code of Conduct[20]; and the *British Columbia Salmon Farmers Association Code of Practice*[21], and *Guidelines for sustainable coastal aquaculture in Belize – coastal zone management for aquaculture development* (Huntington and Dixon, 1996).

It is important that different codes of practice are complimentary and can be applied to specific levels, sub-sectors or even bio-geographic zones. They also need to be developed with the industry to ensure that they are practical and enjoy the support of those who will implement them. It is also important that the use of such codes does not unnecessarily disadvantage minority groups, such as small-holder or extensive aquaculture activities, especially if use of the CoP is linked to eco-labelling.

The framework for a possible Code of Practice for aquaculture in sensitive environments is provided in Section 10.3.

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19 **Codes of Conduct** describe guidance for aquaculture operations in broad terms whilst **Codes of Practice** are voluntary and practical codes designed to standardised and improve the management of aquaculture.

20 http://www.feap.info/FileLibrary/6/FEAP%20Code%20of%20Conduct.pdf

21 http://www.salmonfarmers.org/industry/code.html

4. **Disease exchange and stock movement protocols**: the introduction of diseases and the introduction of alien species on biodiversity have had a profound and largely unquantified economic and ecological impact in Europe. This has recently been acknowledged by the EC, who have proposed a new regulation to permit the use of alien or 'locally-absent' species in aquaculture through a framework that includes (i) procedures for the analysis of the potential risks, (ii) the taking of measures based on the prevention and precautionary principles and (iii) the adoption of contingency plans where necessary (EC, 2006).

5. **Regulation**: there is already extensive regulation within Europe and EU Member States governing land and water use that is relevant to aquaculture, such as the Water Framework Directive. However there is comparably little EU regulation specific to aquaculture, although the amount of Member State regulation varies. For many northern European countries, strict permitting regulation is now a major reason behind the slowdown in the expansion of the industry. It may be that similar controls are considered for fast growing coastal aquaculture development in sensitive areas of the Mediterranean, possibly driven by an overarching regulatory framework from the EC.

6. **Economic and fiscal incentives**: Most business enterprises respond more rapidly and willingly to financial incentives rather than rules and regulations. In countries with a reasonably well-developed and regulated trading system, taxes and tax breaks can be applied with relative ease to encourage particular kinds of behaviour. These approaches were specifically allowed for under Principle 16 of the Rio (UNCED) Declaration, which requires that the costs of environmental damage be internalized, and that the polluter pays.

   Financial incentives or restraints may include the following:

   - Charges related to the issue of operating permits (user fees);
   - Charges related to the rate of production;
   - Charges related to the rate of pollution (pollution taxes);
   - Tradable or non-tradable permits (e.g. a permit to discharge a certain amount of waste, or use a certain quantity of a resource, or to use a certain amount or proportion of environmental capacity);
   - Deposit refund systems (a deposit or bond is deposited as a guarantee against environmental degradation, or to pay for restoration should this be required);
   - Environmental trust funds (similar to deposit refund systems, but allowing for critical spills, accidents etc during normal operation);
   - Subsidies for certain (environmentally friendly) technologies, or a tax or surcharge on less desirable technology; and
   - Legal liability for certain kinds of environmental damage.

7. **Market incentives**: the increasing success of the Marine Stewardship Council's (MSC) standard for 'responsibly managed fisheries' has rekindled interest by European retailers in looking for a comparable standard for aquaculture produce. There are already organic aquaculture standards that ensure various operational and welfare characteristics but one of the most difficult barriers has been the dependence of most European marine aquaculture on high protein diets derived from small pelagic 'feed fisheries'. In a recent initiative, the MSC have launched a partnership with the Soil Association, a leading UK multiple retailer and a seafood processor "to develop certified sustainable sources of fish meal and oil for organic farmed fish diets" (fishupdate.com, April 2006).

7.4.2 Local-Level Mitigation Approaches

On a site-by-site level, or through local management area initiatives, it is possible to reduce the individual and cumulative impacts of aquaculture activities in sensitive environments, especially regarding nutrient loading, the use of chemicals and the introduction of disease. There are a number of stages and mechanisms available to operators:

Location and siting: the location and siting of aquaculture is probably the single most important factor in dictating its environmental impact. For cage farms, this means ensuring the environmental capacity of the site is suitable for the intended biomass and that the risks of impacting sensitive habitats or species are reduced. For land-based farms it is important not to destroy or alter sensitive inter-tidal and supralittoral habitats, as well as ensuring that brackish or saline waters and effluents do not impact local or adjacent soils and wetlands. The main mitigation options include:

Table 43: Mitigation Options for Sea and Coastal Land Sites

Sea cages and rafts	Land-based farms
• Cages should be sited where there is sufficient water exchange • Cage footprint (mooring lines, anchors, etc) outside of physically sensitive sites e.g. biogenic reef structures and sea grass meadows. • Use of cage and raft units should be rotated and sites fallowed. • Operations such as sea lice treatment could be coordinated within a management unit to reduce cumulative stress. • Sites should be outside navigation routes to minimise collision risk.	• Land-based farms should be sited in the supralittoral zone with a suitable buffer zone between it and sensitive habitats, especially bird foraging and over-wintering areas; • Sites should not be placed in freshwater areas unless specific measures are taken to prevent seepage and to protect soils and ground water; • Multiple sites should be planned to avoid contamination of water supply and discharge areas. • Settlement ponds and biofiltration should be considered to reduce suspended solid and nutrient levels, especially during pod drawdown.

Design and construction: once a site has been chosen, sympathetic design and construction can further minimise environmental pressures operating from subsequent operation. The EIA should assess and inform this process and should be considered as an opportunity to improve the efficiency of a site and reduce the potential for expensive retrospective action once the farm has been completed. Whilst cage and raft farm sites can benefit from optimisation of growing units as well as their individual design, land-based units show the greatest potential for integrating environmental management into functional design. Examples of design and construction techniques include:

- Breaking cage clusters into smaller units that are sited in sympathy to sensitive areas
- Use larger cages with lower stocking densities
- Use cut and fill techniques to minimise land take of pond farms, leaving a natural buffer zone around the ponds and supply/effluent canals

Operation and management: the way in which an aquaculture activity is operated and managed will influence the way in which that activity impacts the local environment. This can be considered at two levels, (i) the operational and management practices conducted on site and (ii) the capacity of both managerial and husbandry staff to undertake these activities.

Operational and management practices: there are a wide range of good management practices that can be undertaken to (i) reduce the risk of containment failure, (ii) to reduce the level of nutrient and other inputs into the local environment and (iii) improve the conditions in which the stock live to minimise stress, exposure to pathogens and to improve welfare. There are well established and can be found in the various codes of Practice (see above and Section 10.3) that have been developed for different forms of aquaculture and will not be repeated here. However, when aquaculture is being undertaken in areas within or adjacent to areas of particular sensitivity, the following of best management practice (BMP) is particularly relevant.

Staff capacity: both management and husbandry staff capacity in environmental management can be improved through a combination of skills training and increased awareness. Skills training can include strengthening the ability of managers to develop suitable environmental management policy and guidelines and to install monitoring programmes that are appropriate to the scale and nature of the aquaculture activity. Husbandry staff need to be trained in specific environmental management implementation techniques, as well as have their awareness of the vulnerability of both sensitive habitats as well as the farming operation itself to poor environmental standards.

Feed quality and application management: in the case of intensive finfish culture systems that dominate European aquaculture, the quality of feed inputs and the way in which they are applied is an important factor in dictating the bio-geochemical changes resulting from aquaculture activities. Aquaculture feeds have undergone extensive research over the past thirty years to improve the digestibility of the main protein, carbohydrate and fat components as well as the availability of nutrients. As a result, waste production has been reduced to a minimum, and there is relatively little scope now to improve the availability of feed components through feed formulation. The main sources of waste now come from (i) metabolic by-products, (ii) the undigested and largely inorganic elements of the feed and (iii) uneaten food. Of these, presuming the use of a high quality diet, the former two can mainly be reduced by optimising feeding rates and delivery to improve the overall FCR, even if it reduces to overall growth rate. Therefore farms in sites where there is a need to keep nutrient change to a minimum may need to consider a slightly longer growing period to ensure maximum utilisation of the delivered feed. The later element of reducing uneaten feed has become an important management objective - various approaches have been adopted, including better feed delivery management using computer-controlled, centralised feeding systems. Feeding rates can be further adjusted by the use of underwater cameras and sensors that detect when feed is passing through cage systems and not being utilised by the stock, thus invoking a reduction in feeding rates.

Disease prevention and management: disease prevention and management requires a range of measures from national to farm level. At farm level, again there is a mix of operational practices and capacity issues. At the operational level, it is important to ensure that all broodstock, juveniles or adults are received as certified disease-free and if there is any doubt, undergo a period of quarantine. Systems then have to be in place to ensure that clinical symptoms can be picked up at an early stage and appropriate diagnosis and management responses made. Furthermore, the growing environment needs to be kept within optimal ranges to reduce stress and fish movement e.g. grading or movement between grow-out units needs to be as stress-free as possible. Regarding staff capacity, there needs to be sufficient veterinary skills available and husbandry staff are trained to detect abnormal behaviour or clinical signs that might indicate an emerging problem.

Waste water treatment: land-based farms have the opportunity to modify waste water streams before they are discharged into the environment. Allowing suspended solids to settle by using holding ponds that reduces the velocity of effluents allows a large proportion of organic and inorganic materials to be removed. Dissolved nutrients can also be removed through filtration, with biological techniques such as reed bed systems and algal beds, as well as using bivalve-lined effluent canals. A 36 month project AQUAETREAT is being funded under the Sixth Framework Programme for Research (FP6)'s Collective Research theme to investigate aquaculture effluent treatment technology at a total cost of €1.6 million.

7.4.3 Pressure-Specific Mitigation Measures

The following section provides a series of mitigation measures that might be used to reduce the level (i.e. magnitude, distribution and duration) of the main pressures originating from aquaculture that might impact sensitive environments.

Sedimentation: the impact on the seabed from solids depositions is the most obvious pollution effect of fish farms. Although there are a number of knock on effects such as nutrient enrichment and reduced oxygen saturation across the seabed and in the water column (identified below), these are defined and discussed as separate pressure categories. In this section, the impacts of sedimentation are related to smothering effects. These are particularly important across a number of sensitive habitats and associated species including maerl beds, sea grass beds, mussel bed communities and polychaete worm reefs. Impacts on sandflats and mudbanks may also be particularly significant where these habitats constitute critical habitats. With the resultant impacts on biodiversity, sedimentation is therefore a key issue conflicting with biodiversity aims across all sensitive areas where these habitats are present. Mitigation measures outlined below and those COPs that may be derived from them, should necessarily, therefore, be robust and of high priority.

Physical impacts associated with sedimentation.	Direct impacts related to smothering of habitats (eg serpulids, *Modiolus*) resulting in disturbance or death of organisms or leading to increased risk of disturbance or habitat modification.
Changes in water transparency	Impact on primary producers
Chemical impacts	Changes in oxygen saturation within water column across water/sediment interface and within sediments.
Organic enrichment of seabed/ substratum	Potential knock on effects to nutrient enrichment of the water column.

a) *Sediment disposal* - Environmentally sound disposal of pond/lagoon sediments away from sensitive habitats and any watercourses and in accordance with relevant regulations.
b) *Carrying capacity* – Facilities to meet recommended criteria established for production limits relating to carrying capacity for particular areas
c) *Sediment removal* - Use of settlement basins, borrow pits and other techniques to remove sediments from discharge water. Sediments should not be removed through flushing but rather by mechanical means and subsequent disposal
d) *Feeding regime* - Vigorous control and monitoring required on feeding regime and feed conversion ratios to minimise waste release.
e) *Flood retention* – ponds and lagoons should be designed to contain flood events and thus contain release of sediments

f) *Site location* - Location of site/facilities and effluent discharge within good flushing environment such as areas with adequate tidal flow.
g) *Site Location* – Deep water isolation. Identification and use of suitable deep water sites e.g. sea lochs/ basin features
h) Biomass limits – Biomass limits, imposed by the competent authority and based upon accepted modelling, should be adhered to.

Infrastructure Impacts: preserving the functional integrity of habitats is a high priority across all sensitive areas and is especially important for maintenance of the biodiversity goals also common among these designations. Habitat modification as a result of any activity is therefore inconsistent with the aims of those environmentally sensitive areas discussed in this report. Due to the nature of aquaculture developments, these impacts cannot be completely mitigated but measures should aim to reduce impacts as much as is reasonably possible so as not to constitute an impact on site integrity. This is reflected in the range of recommended mitigation measures below. In some cases, such as within 'no take zones' in Marine Protected Areas, no aquaculture activities would be permitted at all regardless of the efficacy of such measures.

Physical disturbance of habitats by structures.	Due to physical placement and long term securing of structure e.g. anchoring sea pens using cement blocks, risk associated with damage in event of structural failure, or modification of terrestrial habitats to accommodate facilities.
Disturbance of seabed through harvesting	For example in mollusc aquaculture systems where dredging or tools are used to scrape seabed/ substratum
Disturbance along shoreline or of habitats	As a result of shore based activities/ infrastructure such as clearance of existing habitats.
Impacts related to sourcing/capture of wild stock	Impacts on habitats associated with activities such as dredging or through effect of disturbance of trophic interactions.

a) *Sensitive site selection* – site location should avoid any disturbance to essential habitats. For marine or freshwater aquaculture systems these habitats can be defined as 'those waters and substrates necessary for spawning, breeding, feeding or growth to maturity'.
b) *Habitat restoration* – habitat restoration should be initiated following closure of facilities. In some cases this may involve allowing natural succession of habitat while in others, active intervention such as planting, may be required.
c) *Facility Construction* – Facilities should meet construction standards to withstand adverse natural events such as flooding/storm and localised wave and current conditions to a defined occurrence period or condition strength. Net pens should be manufactured to meet or exceed industry standards. Equipment should not be used in conditions beyond manufacturers recommendations. Where floating pens are used, use of moorings should be in accordance with pen manufactures guidance
d) *Maintenance of facilities* – Mandatory routine maintenance or periodic survey of facilities should be carried out in order to ensure and maintain structural integrity of structures.
e) *Harvesting of stock* – Where practicable, a habitat recovery period should be included within harvesting procedures. This might involve introducing fallow periods following harvesting or patch harvesting to leave matrices of disturbed and undisturbed habitat therefore providing source zones for re-colonisation of harvested areas.

f) *Capture of Wild Stock* – Capture of wild stock should allow suitable recovery of habitat such that overall habitat integrity is not compromised. Fishing/capture should be environmentally sustainable and integrated into management of area.

g) *Buffer zones* – Maintain buffer zones between aquaculture facilities and sensitive habitats. Width of zone will be dependent upon scale of facility and subject to mandatory requirements**.**

h) *Extent and distribution of habitats* - In line with Habitats directive requirements, producers in sensitive sites prove must aquaculture operations or development is not having a significant impact on the extent or distribution of designated habitats from an established baseline, subject to natural change.

i) *Development footprint* - Roads, pipelines etc should be constructed to minimise development footprint. This includes those temporary areas used during the construction phase for works offices, material and equipment storage, waste storage etc.

Change in Bio-geochemistry: similar to a number of other pressure categories, water quality parameters are of high importance within environmentally sensitive areas in relation to their impacts upon biodiversity. With maintenance of biodiversity a principle aim across all environmentally sensitive area designations, maintenance of good water quality standards, such as dissolved oxygen, is required for aquaculture facilities.

The adverse effects of nutrient enrichment and subsequent impacts associated with eutrophication within marine systems are widely documented. Impacts associated with sensitive habitats are discussed in section 6. These impacts are typically associated with biodiversity loss, especially in seagrass communities where eutrophication has been linked to the decline of seagrass beds world wide. The impacts of nutrient enrichment on a variety of other sensitive habitats may also be significant, depending upon degree of enrichment, and constitutes an important threat to achievement of biodiversity aims across all protected areas. Aquaculture inevitably results in the enrichment of the water column, with land based systems frequently having as much of an impact as marine systems as tanks or lagoons water are flushed into receiving coastal waters.

Recognising the potential impacts of nutrient enrichment on habitats and species, water quality monitoring is frequently intrinsic to the management of sensitive areas. Article 11 providing for national measures for the protection and conservation of species in SPAMIs for example notes that parties should 'carry out management, planning and other measures to ensure a favourable state of conservation of such species' (http://www.oceanlaw .net/texts/unepmap2.htm). Similar to management criteria across all other designated sites, this should include measures to monitor and mitigate effects of nutrient enrichment.

Through release of N and P direct to water column	Large concentration of N and P in solute form released. Impacts on phytoplankton productivity.
Through release of nutrients from deposited sediments/ faeces/ food waste.	
Through water column	Within confined areas or zones with little water movement such as lagoon culture
Across seabed	Typically associated with decomposition of deposited organic matter.
Due to sediment releases	May be associated with release of anoxic sediments during pond draw down and draining

a) *Nutrient monitoring* – Development of nutrient monitoring standards and indicators to describe the nutrient load from operations. Adherence to discharge consents based on nutrient loads
b) *Control of leakage* - Pond/ dyke compaction or use of liners to avoid seepage and nutrient enrichment of nearby waters.
c) *Effluents* - Strict controls and treatment of effluents from ponds/lagoons/ tanks. Might involve aeration of effluents to increase aerobic breakdown of wastes prior to discharge, thereby reducing BOD of effluent.
d) *Site Location* – Deep water isolation. Identification and use of suitable deep water sites e.g. sea lochs/ basin features.
e) *Biomass limits* – Biomass limits, imposed by the competent authority and based upon accepted modelling, should be adhered to.
f) *Carrying capacity* – Facilities to meet recommended criteria established for production limits relating to carrying capacity for particular areas
g) *Feeding regime* - Vigorous control and monitoring required on feeding regime and feed conversion ratios to minimise waste release.
h) *Flood retention* – ponds and lagoons should be designed to contain flood events and thus contain release of sediments
i) *Discharge control and consents*– Increase use of water re-cycling to limit discharges. This would also precipitate higher standards of water treatment within facilities.
j) *Site location* - Location of site/facilities and effluent discharge within good flushing environment such as areas with adequate tidal flow.

Change in Coastal Processes: among the Environmentally Sensitive Area designations reviewed, maintenance of existing coastal processes is not raised as any of the key aims. As previously highlighted however, the importance of maintaining biodiversity is a key component of the aims of the under discussion. As part of this, coastal processes play a key role in maintaining habitats through such functions as sediment and nutrient transport, and maintenance of salinity and temperature regimes. Even where changes in coastal processes are minor, impacts on habitats may be highly significant. Minor reduction in current velocities, for example, may be sufficient, over time, to result in sedimentation of maerl beds. These habitats rely on water movement to disperse fine sediment particles, and increased sedimentation might be expected to have an adverse impact on maerl and its associated flora and fauna (http://www.UK BAP.org.uk/ UKPlans.aspx?ID=40). Sensitivity assessment of kelp and seaweed communities to water velocities, processes provides a further example of the importance of maintaining coastal processes Suitable hydrological impact assessments therefore constitutes an important mitigation measure in fulfilling the biodiversity aims of environmentally sensitive area designations.

Impact on hydrological processes	Impacts on water supply, water levels or current velocities with knock on effect to sensitive habitats and species.
Impact on sediment transport processes	Impacts resulting in altered erosional or depositional regimes along coast

a) *Hydrological impact assessment* – Assessment required for development of new facilities and extension of existing facilities.

Land and Seascape Modification: reduction in visual impact of an area as a result of developments frequently constitutes a major issue. This is particularly the case for aquaculture facilities which are frequently located in isolated areas, with intrinsic landscape value. A prime example of this is the sea lochs of Scotland which frequently provide ideal potential sites for aquaculture. Of the environmentally sensitive areas discussed in this report, there is little reference to maintenance of landscape value in fulfilment of the aims and priorities of the conventions and regulations that support them. Most of the emphasis is on conservation of biodiversity. Where reference is made to maintenance of landscape value within management plans, this is on the basis of planning policy requirements. World Heritage Sites are an exception to this as these are often selected on the landscape value of an area which is intrinsically linked to the habitats present.

Apart from World Heritage Sites, requirements to mitigate the impacts of aquaculture on the landscape value with a site are minimal. Exceptions to this, however, may occur where land or seascape modifications constitute a detrimental impact to migration of species and thereby the habitats they maintain or are a constituent part of.

Due to the physical presence of structures	Impacts to visual amenity of an area. Potential impact on visual cues within habitat used by migratory species.
Land modifications to accommodate aquaculture	Such as drainage and clearance of wetland systems for pond/ lagoon culture.

a) *Visual impact assessment* – Production of impact assessment guidance should be required of relevant authorities. Careful site selection based on landscape assessments required of all new developments in line with assessment guidelines e.g. Scottish Natural Heritage 'Marine Aquaculture and the Landscape; the sighting and design of marine aquaculture developments in the marine environment'.

b) *Visual impact reduction* – Required employment of measures to reduce visual impact of facilities e.g. use of dark colours, camouflaged netting, submerged or shielded lighting, use of environmentally sensitive screening e.g. planting.

c) *Sight lines* – Aquaculture facilities must show regard for requirements of designated species proving that facilities do not result in a visual impact affecting behaviours. Waders for example require unrestricted views over 200m to allow early detection of predators while feeding and roosting. Infrastructure in specified areas should not result in obstructions to existing view lines, subject to natural change.

d) *Habitat restoration* (as previous)

Disturbance: disturbance of habitats and the species associated with them may be linked to a number of aquaculture-induced pressure categories. Examples include sedimentation, habitat modification and changing coastal processes. 'Disturbance' used in this case, however, is defined by temporary or intermittent, non-physical impacts.

Among the environmentally sensitive area designations, limiting disturbance to habitats and species is a key requirement of the Conservation (Natural habitats & c.) Regulations 1994) as applicable to Natura 2000 site management. Under the regulations the appropriate nature conservation body has a duty to inform relevant authorities of 'any operations which may cause deterioration of natural habitats or the habitats of species, or disturbance of species, for which the site has been designated' (http://www.opsi.gov.uk). In this context, disturbance of critical habitats such as roosting, feeding or breeding sites of designated species constitutes an adverse impact on site integrity. Potential long term consequences of disturbance, especially where critical habitats are affected, might include shift in species distribution and/or abundance and resultant loss of site biodiversity. Where the functional integrity of sensitive habitats is compromised, the habitat itself is also likely to deteriorate.

While the impacts of disturbance on habitats may be more difficult to determine than other pressure categories such as habitat modification and sedimentation, aquaculture induced disturbance constitutes a potentially serious threat. Mitigation measures to reduce disturbance are therefore of high importance. Disturbance reduction may also be 'event managed' i.e. any new or temporary works operations managed to limit disturbance. In this way measures will not be restricted in their application.

Facility construction	Noise disturbance e.g. across feeding/ breeding/ roosting habitats
Impacts resulting from site traffic	Land or water movements that do not constitute habitat modifications. Disturbance impacts include noise, dust, and traffic movements on land and water.
Light pollution	Especially associated with intensive systems. May impact nesting species of birds as well as turtles along important coastal frontages.

a) *Appropriate training* – Environmental awareness training for construction and facility workers and establishment of appropriate reporting routes and mitigation measures in the event of an incident.
b) *Critical seasons* – where practicable, construction of facilities should take place outside of critical seasons such as breeding or over-wintering periods. Work taking place within these periods should minimise high disturbance activities and minimise use of heavy equipment.
c) *Limits on machinery use* – Restrictions should be placed on use of certain types and classes of machinery in proximity to or over critical or sensitive habitats. Examples include drilling rigs, pile drivers, tracked machinery or other heavy machinery. Distance limits should be imposed on use.
d) *Numbers and distribution of designated species* – aquaculture producers must demonstrate that operations are not having a significant adverse impact on the numbers or distribution of designated species such as over wintering bird populations, from an established baseline, subject to natural change.
e) *Presence and abundance of prey species* – across areas designated fro their bird interest e.g. SPA's, the presence and abundance of prey species should not deviate from an established baseline, subject to natural change as a result of aquaculture activities.
f) *Noise reduction* – Equipment that creates noise should be suitably muffled to prevent undue disturbance to species.
g) *Development footprint (as previous)*
h) *Visual impact reduction (as previous):* use of lights should be strictly controlled in proximity to critical habitats. Examples include turtle nesting beaches

Predator Control: the use of the term 'predator' here refers to both actively predacious species, such as seals, as well as foraging species such as mollusc feeding diving and wading birds, both of which groups may exert significant pressure on aquaculture facilities.

Within the range of pressure categories associated with aquaculture, predator control initiatives have comparatively little impact upon sensitive habitats or species. Sites are generally located in areas of low predator abundance to avoid excessive predator pressures which may otherwise may make maintenance of facilities unsustainable. Aquaculture will generally attract predators however and the use of predator control devices will not only have an impact on active predators but also groups of animals that do not predate upon stock. These may include migratory species such as whales and also waders and wildfowl with dietary requirements other that that produced in aquaculture facilities. The range of predator control devices available means that while effectiveness may be similar, impacts on non-target groups may widely differ. (see Section 5.7 Predator control). Although use of predator nets may result in harm or death of species, requiring mitigation to improve animal welfare, disturbance caused by lights or acoustic devices is likely to constitute a greater disturbance impact. Mitigation in this case therefore takes on the importance to site integrity discussed in the previous section.

Acoustic devices	May have impact on bird or mammal species feeding in local areas.
Anti-predator netting	May drown diving birds, seals and porpoises (Ross 1988)

a) *Non-lethal physical deterrents* – Deterrents deployed based on scale of requirement, with physical deterrents used as first line of prevention. Where it is necessary to employ acoustic devices in conjunction with physical deterrents, reactive devices only should be used as these reduce impact on non-target species such as cetaceans.

b) Net requirements - Use of High Tension Predator Nets to avoid entanglement. Periodic checks required to ensure viability and safe operation of equipment.

c) *Site selection* - Selection of sites with low numbers of predators and avoidance of known cetacean migratory routes to reduce disturbance resulting from required predator control.

Chemical Use: although the understanding on use of chemicals in the aquatic environment is still developing, concerns exist over their impacts on non-target organisms and habitats. As for a number of pressure categories previously discussed, concerns over adverse impacts on biodiversity constitute a threat to the aims of the full range of sensitive areas reviewed in this report. Article 2 of the OSPAR Convention, for example, under which a network of MPAs will be established, states that contracting parties shall 'take the necessary measures to protect and conserve the ecosystems and the biological diversity of the maritime area, and to restore, where practicable, marine areas which have been adversely affected' (http://www.ospar.org/eng/html/convention/ospar_conv10.htm).

Mitigation measures necessary to achieve these aims, with respect to use of chemicals, should therefore be developed. Of these measures, monitoring requirements are particularly important, with information providing feedback for further development of chemical compounds and development of appropriate mitigation measures and COPs.

Structural materials	Anti-foulants on solid surfaces and use of pesticides on nets and ropes.
Disinfectants, pesticides and anti bacterial agents.	Prophylactic applications or applied direct to system. Impact route typically on sediment fauna.

a) *Universal legislation on chemical use* – Chemical use should meet uniform standards and application limits across the EU

b) *Specialist facilities* – Specialist facilities for cleaning and application of antifouling to nets and structures to reduce environmental impact of chemicals

c) *Maximum biomass treatments* – Limiting biomass on the basis of consent limits for sea lice/ pathogen treatments.
d) *Vaccination* – To maintain fish health and welfare while reducing antibiotic use
e) *Discharge control and consents*– Increase use of water re-cycling to limit discharges. This would also precipitate higher standards of water treatment within facilities.
f) *Monitoring* - Appropriate monitoring should be carried out to enable determination of any impacts that might be linked to chemical use. Resulting information should be shown to be used in development of mitigation measures and evolution of COPs.
g) *Suppliers responsibility* – suppliers should be responsible for ensuring that all feeds meet the requirements of EU legislation designed to limit presence of such contaminants.

Pathogen transmission: Section 6 provides a summary of the general sensitivity of key habitats to the principle pressures associated with aquaculture. Of the habitats discussed, transmission of disease and parasites is linked to three habitat types;

- mussel bed communities
- sandflats, mudbanks and sandbanks
- seagrass beds on sublittoral sediments

Of these, sensitivity of mussel beds and sand flat, mudbanks and sandbanks to transmission of disease and parasites is ranked as low. Seagrass beds are ranked as highly sensitive to this pressure category however, with extensive problems having been caused, for example, by the introduction of the brown fucoid seaweed *Sargassum muticum*. Seagrass beds are among the most highly productive marine habitats, supporting a wide variety of invertebrate species as well as significant populations of birds as well as providing spawning and nursery areas for a variety of fish including commercial species. Loss or damage to seagrass beds therefore constitutes a threat to the biodiversity aims of all sensitive areas. Statutory site designation plays an important part in the conservation of this habitat and many of the best examples throughout Europe, have been designated as SACs, SPAs and Ramsar sites for example, forming the principle component of management plans.

Development of a set of suitable mitigation measures to prevent degradation of seagrass bed communities is therefore of high importance. Because disease and parasites may be readily transferable and spread over considerable distances, mitigation measures and COPs to prevent the transmission of disease and parasites, should not, however, be restricted to aquaculture developments near sensitive habitats, but be implemented across all developments.

From introduced alien species	
From native species	Intensive farming practices frequently provide opportunity for amplification of diseases or parasites.
Associated with poor water quality	Environmental problems such as poor water quality or other stressors contributing to the outbreak of disease.

k) *Management agreements* – Encourage the development of management agreements with other local producers in order to co-ordinate fallowing times and disease treatments. Each producer should provide a written undertaking to observe the provisions of the strategy. The management group should agree on a number of undertakings such as, the monitoring protocol and frequency of monitoring and timing and criteria for treatments.

l) *Site location* – Sites should not be located close to essential habitats or within bottle necks of migratory routes such as near the entrance to spawning rivers. This will avoid location of facilities with high densities of wild populations.

m) *Preventative approach* – A preventative approach to disease control should be demonstrable by every producer. This is likely to involve adherence to a number of the mitigation measures previously highlighted.

n) *Handling mortalities* – Where practicable mortalities and injured individuals should be removed immediately and disposed of on shore via an ensiler system. Checks for mortalities and injured individuals should therefore be conducted on a regular basis. Any mortalities should be reported. And unexplained mortalities reported to other producers and competent authority.

o) *Feed standards* – Where fish or parts of fish are to be used as feed, producers are required to meet a standard of processing to ensure a microbiologically safe product.

p) *Effluent control* – Introduce mandatory treatment of all discharges to destroy pathogens. This may involve fallow periods following removal of hosts/ farmed species.

q) *Waste minimisation* – Producers should reduce health risks to stock by ensuring good feeding practices that minimise waste.

r) *Fish movements* – Producers should obtain the highest level of certification or assurance that brood stock is free from pathogens. The same assurances should be required for fish movement between sites.

s) *Quarantine* – Wild caught introductions from both outside the EU and from different biogeographic regions (e.g. Mediterranean Basin and Irish Sea) should be quarantined for a minimum period within a land based site, with appropriate disinfection system. Testing for notifiable and other diseases should be undertaken on individuals that show morbidity or mortality.

t) *Rotation of treatments* – producers should use as wide a range of treatments as possible, in rotation, in order to reduce the risk of resistance among viral or parasitic infestations.

u) *Movement of equipment* – movement of equipment should be kept to a minimum and equipment should be site specific as far as is possible to avoid transmission of diseases. Where equipment movements are necessary between designated areas, cleaning and disinfection should be undertaken.

v) *Preventing movement of fish* – ponds and lagoon systems should use appropriate screening on both inflow and outflows to prevent passage of stock. Such a precaution relates not only to reducing risk of disease transmission, but also to reducing risk of interbreeding and escapes of exotics.

w) *Facility Construction - (as previous to reduce escapes)* Also use of adequate navigational lighting to minimise collision risk with vessels.

x) *Flood retention* (as previous) Will also act to effectively contain fish during such flood events.

Interbreeding: although impacts arising from interbreeding are well documented, there appears to be little direct reference to this pressure category within management plans. Most management plans and the regulations or conventions upon which they are based do, however, note the importance of maintaining species composition. With reference to reef habitats, for example, the favourable condition table of the South Wight Maritime European Marine Site (English Nature 2001) notes that 'species composition is an important contributor to this sub-feature (kelp forest communities) and therefore the reef as a whole'. Guidance on the aims of Biogenetic reserves, similarly states the importance of 'protecting specimens of flora and fauna which together constitute typical aspects of a given region' (http://ims. wcmc.org.uk/IPIECA2/conven/conven_ biogen.html). The risks that interbreeding may pose to these aims are clear and mitigation measures to reduce this risk may be considered of direct relevance across the full range of sensitive sites.

Farmed populations may be established using few fish	Reduces genetically effective population size. Potentially reduces reproductive fitness of wild population and loss of genetic diversity, further reducing fitness

a) *Contingency Planning* - Producers required to demonstrate establishment of emergency contingency planning for escapees. Report routes to relevant authorities and local facilities should be firmly established.

b) *Preventative measures* – preventative measures to reduce risk of escapees should include routine auditing of maintenance checks which may include mooring and net inspection. Equipment used should be designed to withstand local conditions such as weather and currents.

c) *Hatchery techniques* – Generation gap between farmed individuals and wild caught stock should be kept within specified limits to avoid extended genetic migration. As an alternative, establishment of farm populations should be from large population of fish to promote genetic diversity. Selection for wild traits and regular introduction of new breed stock should be promoted.

d) *Sensitive site selection* – site location should avoid any disturbance to essential habitats. For marine or freshwater aquaculture systems these habitats can be defined as 'those waters and substrates necessary for spawning, breeding, feeding or growth to maturity'.

e) Facility Construction – Facilities should meet construction standards to withstand adverse natural events such as flooding/storm and localised wave and current conditions to a defined occurrence period or condition strength. Net pens should be manufactured to meet or exceed industry standards. Equipment should not be used in conditions beyond manufacturers recommendations. Where floating pens are used, use of moorings should be in accordance with pen manufactures guidance. Also use of adequate navigational lighting to minimise collision risk with vessels.

f) *Preventing movement of fish* – ponds and lagoon systems should use appropriate screening on both inflow and outflows to prevent passage of stock. Such a precaution relates not only to reducing risk of disease transmission, but also to reducing risk of interbreeding and escapes of exotics.

Introduction of alien species: Invasive alien species have been identified as one of the key causes of loss in biodiversity for the EU and the world at large (Commission of the European Communities 2006. Proposal for a council regulation concerning use of alien and locally absent species in aquaculture). In response to this threat, and in support of the EU Biodiversity action plan for fisheries, the Commission of the European Communities 2006, undertook to 'thoroughly evaluate the potential impact of non-indigenous species in aquaculture and to promote the application of the International Council for the Exploration of the Sea (ICES) Code of Practice on introductions and transfer of marine organisms and the European Inland Fisheries Advisory Commission (EIFAC) Code of Practice and Manual of Procedures for consideration of introductions and transfers of marine and freshwater organisms'.

These measures would be in support of key aims for management of sensitive areas discussed in this report such as the examples given from Natura 2000 sites above, which in turn are supported by the Habitats Directive, which requires Member States to "ensure that the deliberate introduction into the wild of any species which is not native to their territory is regulated so as not to prejudice natural habitats within their natural range or the wild native fauna and flora and, if they consider it necessary, prohibit such introduction". Article 13 of the Protocol for Conserving Protected Areas and Biological Diversity in the Mediterranean (http://www.oceanlaw.net/texts/ unepmap2.htm) makes similar provision, noting that, 'The Parties shall take all appropriate measures to regulate the intentional or accidental introduction of non-indigenous or genetically modified species to the wild and prohibit those that may have harmful impacts on the ecosystems, habitats or species in the area to which this Protocol applies.

With direct links to transmission of disease and parasites, mitigating the impacts of exotic species introductions is clearly intrinsic in maintaining biodiversity and natural habitat and species compositions. The adoption of recommended measures should therefore be of high priority with development of COPs in line with the Habitats Directive requirements across all sensitive areas.

Genetic difference from wild populations	Interbreeding resulting in fitness reduction of offspring.
Habitat alterations	Exotic species may invade, establish and change habitats to the detriment of native species.
Trophic alterations	Impacts on population dynamics of native populations as a result of increased food competition or direct predation
Spatial alteration	Displacement of wild populations from habitats.

a) *Restrictions on exotics* – Developments should comply with mandatory restrictions on exotic species use across all habitats unless containment is assured e.g. within land based closed systems. Restrictions should also apply to highly selected stock.
b) *Risk assessment* - All imports of exotics should require a documented risk assessment. Release of stock should be limited to specified trial areas and contingency plans developed to deal with unforeseen impacts.

8 CASE STUDIES OF EUROPEAN AQUACULTURE IN SENSITIVE ENVIRONMENTS

The main thrust of the report to this point has been examining the main pressures originating from European aquaculture and the sensitivity of key Habitats and Birds Directive species and habitats to these. This current section looks at four different examples of European aquaculture on sensitive environments and determines the experienced and conflicts involved and the lessons that can be learned.

Four different examples are examined:

1. Cage Salmon Farming in a Scottish Sea Loch
2. Raft Mussel Culture in a Galician Ría
3. Extensive Lagoon Aquaculture in Italy
4. Sea Bass and Sea Bream Cage Farming in the Mediterranean

These systems are quite different but all take place within areas of considerable beauty and nature conservation importance. Two examples of cage farming are used – this is because cage farming accounts for the vast majority of European coastal aquaculture production and secondly because the two locations are very different – the Scottish salmon farming example is a strongly tidal area with rocky reefs whilst the Mediterranean sea bass and sea bream farm has lower current speeds and extensive sea grass beds.

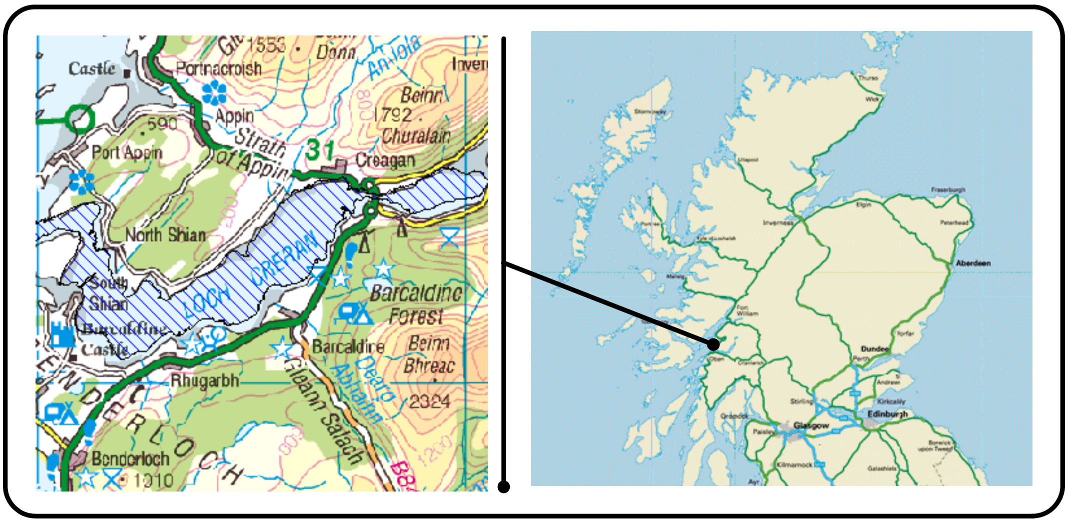
8.1 CAGE SALMON FARMING IN LOCH CRERAN, SCOTLAND

8.1.1 Background

This case study examines a typical northern European cage farm for Atlantic salmon (*Salmo salar),* a species that accounts for over 70% of all marine finfish farmed in Europe. The farm is located in Loch Creran, in the Argyll and Bute region of Western Scotland in the UK, together with mussel and oyster shellfish farming operations.

Location: Loch Creran is a small sea-loch situated on the north-west coast of Scotland (56º31 N, 5º21W), approximately 15 km north of the town of Oban, Argyll (see Figure below). The loch connects to the larger fjord Loch Linnhe and eventually to the water of the NE Atlantic Ocean across the wide Scottish continental shelf. Its longitudinal axis is in an approximately WSW – ENE direction (Jones, 1979).

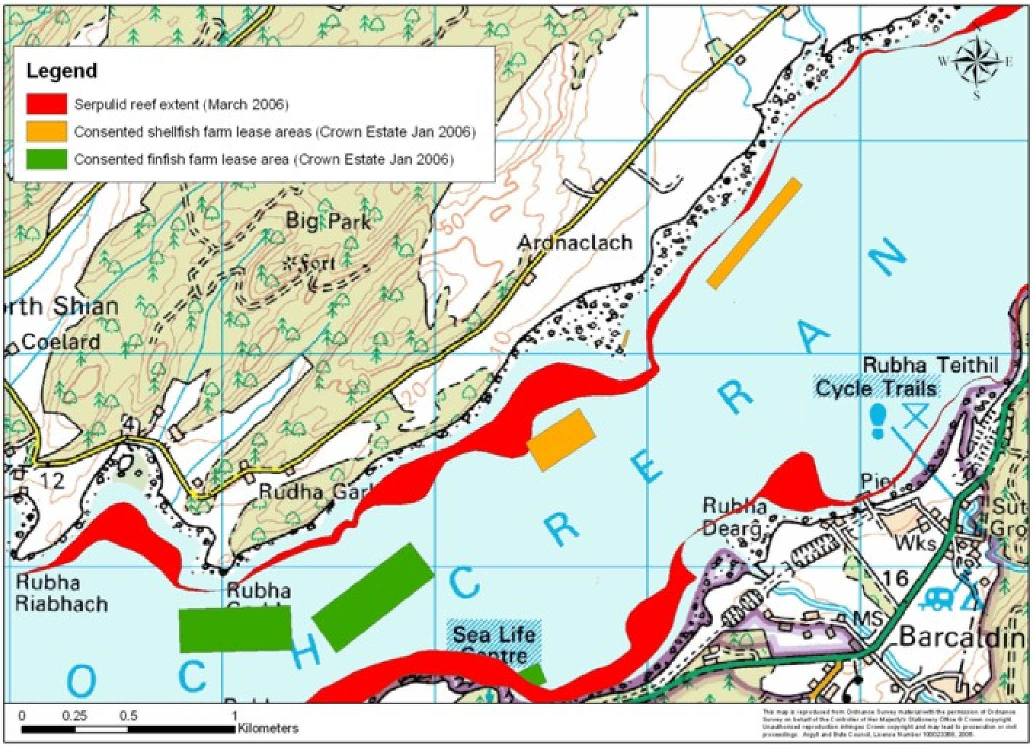
Figure 12: Location of Loch Creran



Aquaculture: Loch Creran has been used for aquaculture since Golden Sea Produce started salmon farming there in the 1970s and subsequently to the Hydro Seafoods GSP, who established the processing plant at South Shian. Hydro Seafoods GSP held a biomass of up to 2,000 tonnes of salmon in the loch at two alternate sites plus another small independent site near South Shian. The original Hydro salmon site was located in the bay between Rubha Riabhach and Rubha Garbh on the north of the loch but a second site was later brought into operation near the sill between the Barcaldine and Shian Basins in the middle of the loch. These two sites were used in rotation until the beginning of the Infectious Salmonid Anaemia (ISA) crisis in 2000. Salmon farming has been restarted by Scottish Sea Farms Ltd (SSF) in 2002 who have a maximum consented biomass of 1,500 tonnes. SSF's initial site was close to the Serpulid reef areas but has been moved to 23-25 m of water, just outside from the reef areas (which are mainly in 10-13 m water depth).

In the 1980s, 1990s and 2000s, some bivalve farms were also introduced into the loch. There is commercial interest in harvesting oysters *(Crassostrea gigas*) and mussels from the water, with seven Crown Estates Commission (CEC) leases having been granted. The Food Standards Agency has given the area an A classification (November to June) and B classification (July to October) for the harvesting of oysters. A restricted area towards the west of the loch is A classification (August to June) and B classification (July) for mussels. The Caledonian Oyster Co Ltd started farming oysters in Loch Creran in 1995. The company farms the Pacific oyster or *Crassostrea gigas*, which does not breed naturally in Scottish waters. This company also has its own depuration facilities on site in Loch Creran. Rubha Mor Oysters started farming oysters in Loch Creran in 2001. Creran Oysters and Isle of Shuna Shellfish are also growing mussels in Loch Creran.

Figure 13: Siting of Loch Creran Aquaculture in Relation to Serpulid Reefs



Source: Scottish Natural Heritage (unpublished)

Management practices details: SSF currently have a consents to keep up to 1,500 t of salmon in Loch Creran. Two sites are leased and are fallowed on a 1:1 basis. The operational site has sixteen 70m circular cages. Smolts are sourced form three different stocks: Lakeland (broodstock sites in Argyll, Scotland and Unst in Shetland), Knock (Isle of Mull, Argyll) or Loch Frisa (Tobermory, Isle of Mull in Argyll). SSF uses Biomar salmon feeds that are either kept on-site in a barge or offsite at Barcaldine Pier and transported to the farm by boat. Feeding is almost entirely by machine (a Storvik Quattro system with feed back loop, or by feed blower). Each site is operated for a two year period – smolts are stocked in the spring of year 1, farmed for approximately 22 months, then the cages are moved and restocked in spring of year 3. Fish are harvested by vacuum pump into a service boat and then processed locally at South Shian.

8.1.2 Surrounding environment and conservation interests

General description of surrounding environment: Loch Creran, situated at the northern end of the Firth of Lorn, is a fjordic sea loch with a constricted opening into the Lynn of Lorn at Eriska. The loch has a mean depth of 13.4 m and a low water area of 13.3 km². Loch Creran is divided into a large lower basin and a small upper basin, separated by silled narrows at Caolas Creagan. The lower basin is further divided into three basins of 14 m, 27 m and 49 m maximum depths. Spring tidal currents in excess of 4 knots occur over a shallow rocky sill at the loch entrance. The loch is typically a well-mixed system although temperature and salinity gradients are common, particularly during periods of high rainfall or snow-melt. Salinities in the lower basin of the loch are generally in the range of 30-33‰ and temperatures range from a low of around 6°C to a high of 13-15 °C. Loch Creran is very sheltered from wave action; this is reflected in the muds and fine sands that characterise the bottom sediments. The mean freshwater input into the loch is 1/70 of the mean tidal inflow, which is 1/7 of the volume of the loch system per cycle of the predominantly semi-diurnal tide (Tett and Wallis, 1978).

Loch Creran is situated in a region of the Western Highlands of Scotland which is sparsely populated. Only two small centres of habitation are present in the immediate vicinity of the loch: South Shian and Barcaldine. A few farms are also scattered on the catchment area. Domestic sewage is therefore unlikely to be of significant importance in terms of nutrient inputs in the loch.

In the 1970's a seaweed processing factory was in operation at Barcaldine. The composition of the effluent was unknown but it was assumed that significant quantities of carbon, particulate organic phosphorus and nitrogen, and dissolved organic and inorganic nitrogen and phosphorus were present. Jones (1979) showed that this plant, following an increase in the scale of its operations, had a potential impact on the quality of the water in Loch Creran through the appearance of decaying particulate material in the intertidal region close to the factory outfall pipe. The factory stopped all activities in the 1980's.

Conservation interests: Loch Creran is an interesting site because of the unique nature of the conservation interest and the varied nature of the activities in the area which include aquaculture and processing, forestry, farming, fishing, recreation and tourism. Loch Creran is designated as a Special Area of Conservation (SAC) for its biogenic reefs of the worm *Serpula vermicularis* and Horse Mussel (*Modiolus modiolus*) beds. *Serpula vermicularis* only form reefs in four sites across Europe, the other three being in Ireland and Italy. The greatest extent of Serpulid reefs occurs in Loch Creran (Moore, 1995). These biogenic reefs increase habitat complexity and are colonised by an abundant and diverse faunal assemblage, including bryozoans, ascidians and sponges. Localised areas of bedrock reef, which support further species-rich assemblages, are also included within the site. Two Habitat Directive Annex II species, the otter (*Lutra lutra*) and Harbour seal (*Phoca vitulina*) are also resident in Loch Creran.

The conservation objective for the loch is to avoid deterioration of the qualifying habitat (reefs) thus ensuring that the integrity of the site is maintained and the site makes an appropriate contribution to achieving favourable conservation status for the qualifying interest.

The objective is to ensure for the qualifying habitat that the following are maintained in the long term:

- Extent of the habitat on site
- Distribution of the habitat within site
- Structure and function of the habitat
- Processes supporting the habitat
- Distribution of typical species of the habitat
- Viability of typical species as components of the habitat
- No significant disturbance of typical species of the habitat

In addition to this marine site, the Glen Creran woods on the eastern side of Loch Creran are protected as a SAC, the woodland being of outstanding importance for the rich communities of mosses and lichens. The Lynn of Lorn is also designated as a National Scenic Area (NSA). The geological Special Site of Scientific Interest (SSSI) at South Shian and Balure is on the western edge of Loch Creran. Another geological SSSI at Clach Tholl, near Port Appin is just out with Loch Creran.

8.1.3 Potential Conflicts and Issues

Finfish and shellfish aquaculture are specifically identified as two of a number of operations to be considered by relevant authorities is provided by Scottish Natural Heritage (SNH) with respect to Loch Creran Marine SAC in fulfilment of the requirements under Regulation 33(2)(b) of The Conservation (Natural Habitats, &c.) Regulations 1994 (as amended by The Conservation (Natural Habitats, &c.) Amendment (Scotland) Regulations 2004). The advice identifies those operations, either on or affecting the SAC, which may cause deterioration of the marine natural habitats or the habitats of species, or disturbance of species, for which the site has been designated, including operations that may not be currently affecting the Loch Creran marine SAC. As can be seen below, concerns is raised over the possible impact from bio-geochemical change, physical impacts as well as the introduction of non-native plants and animals.

Table 44: Sensitivity and Vulnerability of Loch Creran SAC 'Reefs' to Aquaculture

Operations	Comments
Finfish farming	Finfish farming has the potential to cause deterioration of reef habitats and communities through changes in water quality, smothering from waste material, physical disturbance (in the case of rocky reefs), and physical damage (in the case of more fragile biogenic reefs) from mooring systems. There is also potential for accidental introduction of new non-native species and increasing the spread of existing non-native plants and animals (e.g. *Caprella mutica* Japanese skeleton shrimp), which are already widely distributed in the UK. Invasive species have the potential to cause deterioration of the qualifying interest by altering community structure and quality. The associated environmental effects mentioned above are usually localised but the reduced water exchange within Loch Creran may exacerbate these effects and cumulative impacts should be considered.

Operations	Comments
Shellfish farming	This activity has the potential to cause deterioration of the reef habitats and communities through physical damage (e.g. installation of mooring blocks and continued scouring by riser chains) and changes in community structure caused by smothering from pseudo-faeces (undigested waste products) and debris (including dead shells) falling from the farm. There is also potential for accidental introduction of new non-native species and increasing the spread within the UK of existing non-native plants and animals (e.g. *Sargassum muticum* Wireweed) through importation and translocation of shellfish stocks. Invasive species have the potential to cause deterioration of the qualifying interest by altering community structure and quality. The associated environmental effects mentioned above are usually localised but the reduced water exchange within Loch Creran may exacerbate these effects and cumulative impacts should be considered.

Source: SNH, 2006

To date, there have been no impacts from aquaculture that have threatened the conservation objective of the Loch Creran SAC, although it is has proved difficult to conduct a cumulative impact assessment (Jane Dodds, SNH, pers. comm.). A brief review of work done on aquaculture-related impacts in Loch Creran is show below:

Sedimentation: although there is some degree of sedimentation associated with aquaculture activities, especially finfish farming, it is believed that its impact is unlikely to affect to function of the reef community (Nickell *et al*, 2003). Research work assessing these impacts is currently taken place by Moore and colleagues at Heriot-Watt University, Edinburgh (C. Moore, pers. comm.).

Change in bio-geochemistry: possibly increased BOD but currently unknown.

Change in coastal processes: no obvious change.

Visual land and seascape modification: fish farm has a slight visual impact, fish processing plant based in South Shian.

Disturbance: everyday activities are unlikely to impact the conservation objectives of the SAC. Before the relocation of the mussel farm there may have been some physical impact from the mooring chains.

Predator control: the salmon farm sites use ultrasonic seal repellent devices.

Chemical use: A number of authorised medicinal treatments are currently used in the control of sea lice in the Scottish marine salmon farming industry, some for administration as a bath treatment others as an in-feed treatment. For bath treatments, chemotherapeutants such as 'Excis' (active ingredient: cypermethrin), 'Salmosan' (azamethiphos) and 'Salartect' (hydrogen peroxide) are used. For such treatments the fish within the cage are surrounded with a tarpaulin and the chemical is added to the seawater. After the specified treatment period the tarpaulin is removed and the spent solution is released into the environment. The other licensed treatments 'Calicide' (active ingredient: teflubenzuron), and 'Slice' (emamectin benzoate) are administered in the form of treated feed. Following their release, all of these compounds are diluted and dispersed by tidal and wind-driven currents and are broken down eventually to harmless by-products by natural processes. It follows therefore that, during this process, the detection of low concentrations of residues in seabed sediments is not unusual, resulting from the legitimate use of these compounds to treat sea lice infections in full compliance with the relevant discharge consent.

A screening survey conducted by the Scottish Environmental Protection Agency in 2003 (SEPA, 2004) examined sea lice treatment residues in sediments underneath 26 cage farms sites in Scotland, including Loch Creran (the largest of the farms sampled). This showed the following:

- Cypermethrin (consented) - <0.03 μg/kg (dry weight), well below the predicted no effects concentration (PNEC) of 2.2 μg/kg.
- Teflubenzuron (consented) - was not detected in any of the samples. It is reasonable to assume that the allowable effects area maximum allowable concentration (MAC) of 0.002 mg/kg would not have been breached.
- Invermectin (not permitted) – not found in Loch Creran.
- Emamectin benzoate (consented) – found at 13 of the 26 sites, including Loch Creran. Loch Creran's level of 10.2 μg/kg (wet weight) exceeded the trigger value of 7.63 μg/kg applying within the AZE, probably due to the Slice treatments within 6 weeks prior to sampling).

Pathogen transmission: unknown. Wild salmon and sea trout are at risk from infective larval sea lice that may be associated with marine salmon farms (Black *et al*, 2002).

Inter-breeding with wild organisms: unknown but "escapes from salmon farms …. constitute a major threat to wild populations" (Black *et al*, 2002). This area of the UK is an important regional habitat for *Salmo salar* (an Annex II species) populations but no SACs designated for this species are in the immediate vicinity.

Introduction of alien species: unknown but unlikely in the case of salmon farming.

8.1.4 Management and Mitigation Process

The farm is fully aware of the sensitivity of the loch and its environs. One of the original sites was close to the Serpulid reef areas but has now been moved to 23-25 m of water, just outside from the reef areas (which are mainly in 10-13 m water depth) after a formal public consultation exercise. The farm is also aware of the damage that moorings and risers can cause, and therefore (i) ensures that all moorings are in greater than 15 m water depth and (ii) care is taken in locating and moving mooring systems to avoid damage to any of the reef structures (Sally Davies, SFF, pers. comm.).

8.2 RAFT MUSSEL CULTURE IN RÍA DE AROUSA, SPAIN

8.2.1 Background

The cultivated species in Mussel rafts is *Mytilus galloprovincialis*, Lamarck, 1819. Mussel rafts are located offshore in the bays called *rías (Ares, Muros, Arousa, Pontevedra and Vigo)*, ordered in 84 polygons, holding in total more than 100 Ha.

Production System:

Culture begins when farmers collect mussel seed, mainly from natural beds (60-70%); the remainder from the collector ropes hung from their rafts. Farmers suspend the mussels from their rafts: they take the seed to the rafts, keeping it moist, and attach it to ropes within 24 hours after collection. To collect seed from the rafts, farmers use special nets made from old fish nets and suspend them during March and April. Mussel farming can classify as an intensive cultivation system.

The traditional raft system consists in a wooden structure with rectangular shape, size is around 500 m², supported by floats (four or six), constructed of steel covered with fibreglass or polyester, or filled with expanded polyester. Farmers secure the rafts with one or two iron chains and a 20 tonnes concrete anchor. In protected areas with little boat traffic, they use only one mooring chain. Two chains are better in exposed areas or when the rafts are near the shore or heavy boat traffic. The rafts are located together, but separated from each other by about 80-100 m in groups called polygons.

Farmers attach the seed to the ropes by hand, or with a machine which secures it with a special cotton or rayon mesh; this mesh disintegrates within a few days. By then, the mussels have secreted new byssus and have attached themselves to the ropes. Farmers attach from 1.5-1.75 kg of seed/per metre of rope, and the average weight of seed for each rope is 14 kg. Each raft has 500 ropes maximum. Every 30-40 cm, wooden or plastic pegs 20-30 cm long are inserted between the strands of the ropes to prevent the clumps of mussels from sliding down. Farmers attach from 1-3 ropes/m² of raft. This distribution allows an adequate flow of water rich in food for the mussels, and prevents the mussel ropes from touching each other. Farmers install the ropes mainly from November to March.

The third step (after obtaining the seed and attaching it) is thinning, which has to be done to prevent the mussels from falling off in rough weather; thinning also encourages rapid and uniform growth. Farmers do this when the mussels are half grown (shell length 4-5 cm) after 5-6 months of growth, usually from June to October. The mussels from each original rope are attached to two to four new ropes with cotton or rayon netting.

Mussels of commercial size can be harvested at any time but the main harvest is from October to March, when market demand is high and their condition is best. Meat weights can approach 50% of total wet weight when the mussels are in best condition. When a large percentage of mussels is close to spawning or just past spawning, harvesting should wait until they are in better condition. Production can also be defined as about 15 kg of mussels per metre of rope. Annual losses (natural mortality and handling) have been estimated at 15%.

The average raft production is between 60-90 t per year, 40% of it for fresh consumption and 60% for processing. The cultivation cycle has a duration between 12-16 months. Commercial size depends on the mark*et al*though the most popular is around 7-7.5 cm.

The mussels farming by using raft technology is under regulatory limits, thus the maximum number of ropes hanging in each raft are 500 and the maximum length of rope is 12 metres. The maximum area of the raft is 500 m² with a maximum length side of 25 metres.

Management practices: every mussel producer has a boat equipped with a basket and crane to raise the ropes as well as specific equipment to carry out the different tasks involving mussels culture. Special machinery has been developed to help with the various culture practices, especially with the wrapping of spat to the ropes, and grading.

For harvesting, farmers use a crane to raise the ropes to their boat, where the mussels are separated and graded by rubbing them over a grid of iron bars. They are then washed clear of small mussels, silt, empty shells, ascidians, and other unwanted organisms.

Mussel producers use the boat desk as work place: there they prepare the seed ropes, later when the mussel size achieve 4-5 cm they distributed in 2 or more ropes to help a good growth and finally the harvesting.

Mussel farming in Galicia reflects the smallholding, which is characteristic of land farming in the region. Mussel farming being often a business ruled by the members of a single family. Most of the mussel growing firms have an average number of rafts ranging from 1 to 4. About 30% of rafts belong to one owner and not more than 25% of rafts belong to people who own more than 3 rafts. A very few companies own more than 10 rafts and the biggest one around 80.

The official data from 2004 give about 3,537 mussel rafts with a production ranking of 292,316 t per year that represent the 95% of the aquaculture production in Galicia and the 89% of the total aquaculture production in Spain. The mussels industry represent around 8,500 full time and 3,000 part time jobs. The annual turnover of the mussels industry can overtake €132,000,000. Around this industry have been created other such as suppliers of appropriate equipments, depuration plants, processing industry, etc., that can represent around 4,000 indirect jobs.

8.2.2 Surrounding Environment and Conservation Interest

In Galicia there are several natural areas, around the 12 % of its surface corresponds to protected zones included in the Natura 2000 network. In the Atlantic coastline there are the five bays *(rías)* where there are located mussel farms. This coastline hold four protected zones classified as National Park (Cies Islands, Ons Islands, Cortegada Island and Corrubedo dunes) relevant habitats as estuaries (wetland RAMSAR), rocky shores, coastal lakes, dunes and sand flats exposed during low tide classified as SACs, Special Protection Areas (SPAs) and Protection Birds Interest Sites (ZEPAs).

General description of surrounding environment: the Atlantic coast of Galicia characterises by deep fjord-like tidal inlets known locally as "rías". Rías are elongated estuaries that penetrate into the west coast of Galicia (northwest Spain) and are interspersed with sandy bays and rocky headlands. Mussel farming is mainly placed in the bays of Galicia and the major concentration is registered in Arousa bay with over 2,400 rafts.

Conservation interests: the conservation interests of the main Galician bays are as follows:

Location	No. of mussel rafts	Conservation interests
Vigo Bay 42º35´-42º15´N and 8º95-8º55´W	< 500 mussel rafts (bateas).	Cies Islands is a Natural Park and is included in the Atlantic Islands National Park as well as SAC and ZEPAs (Protection Birds Interest Site). Land surface 455.55 Ha and marine surface 534,78 Ha. (42º13´10´´N-08º54´15´). San Simón Island is a SAC.

Location	No. of mussel rafts	Conservation interests
Pontevedra Bay 42º45´-42º25´N and 8º85´-8º69´W	< 400 mussel rafts (bateas).	Ons Island is Natural Park included inside Atlantic Islands National Park as well as ZEPAS (Protection Birds Interest Sites). Land surface 443,42 Ha and marine surface 480,37 Ha (42º23´N-08º56W)
Arousa Bay *42º68´-42º44´N and 8º77´-9º03´W*	> 2,000 mussel rafts (bateas)	Wetland – RAMSAR Umia- Ila de Arousa- O Grove. Surface 2,561 Ha (42º27´11´´N-08º51´53´´W). SAC & ZEPAS Cortegada Island included inside the Atlantic Islands National Park Wetland– RAMSAR Corrubedo Dunes. SAC & ZEPAs (42º34.3N-9º4.2W) Sálvora Island – SAC & ZEPA (42º28 N-9º0.8W)
Muros –Noia Bay – 42º60´-42º80´N and 8º90´-9º15´W	<200 mussel rafts (bateas). Surface 550 Ha	Monte & Lagoa de Louro is a SAC. Noia's Bay – Natura 2000 Network
Ares-Betanzos Bay	< 200 mussel rafts (bateas)	Abegondo- Cecebre SAC

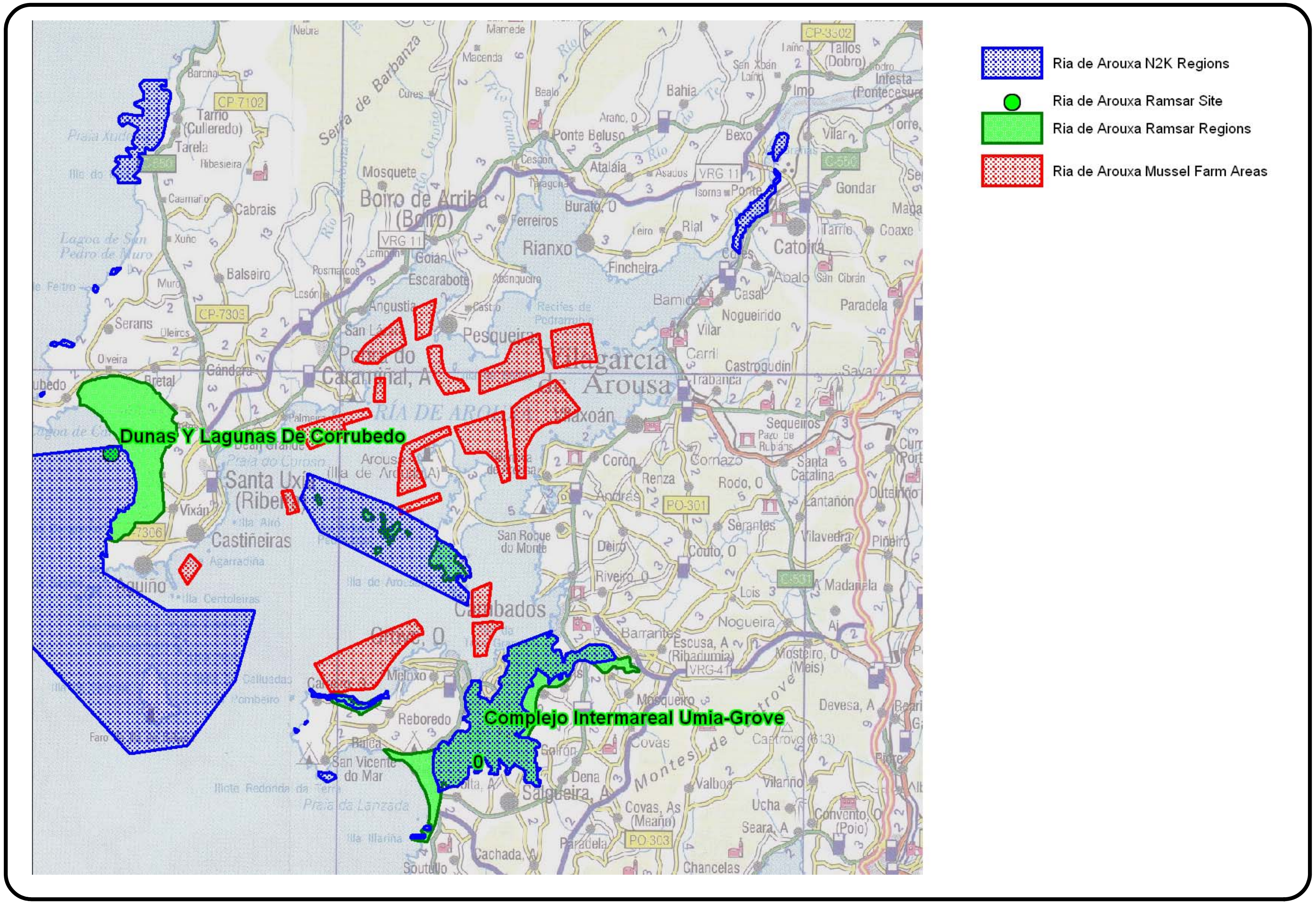
For this case study, we will concentrate on one particular area, Ria de Arousa.

The Ría, situated between 42,44º-42,68º N and 9,05º-8,77º W, penetrates into the west coast of Galicia around 33 km SW-NE. Just in the mouth of the bay is located the Sálvora Island. There are fresh water inputs from three rivers located in different parts of the *ría*. The main fresh water input comes from the Ulla's river on the sandbanks at the bottom of the bay. The second river in magnitude is the Umia at the southwest slope forming the wetland Intertidal Complex Umia – O Grove (Comlexo Intermareal Umia-Grove). The third river is called Beluso that flows into NE slope.

Figure 14: Mussel rafts in Ría Arousa

The Ría de Arousa has been used for aquaculture since 1940´s, when it was installed the first mussel raft. There are around 2,400 mussel farms located at the Ría de Arousa ordered in 24 polygons placed from the mouth to the head of the estuary (see Figure overleaf).

Figure 15: Ria de Arousa – Location of N2K and Mussel Farming Areas



Sensitive areas: there are a number of sensitive areas within Ria Arousa.

Name	Figure of protection	Natura 2000	Note
Complexo Intermareal Umia-O Grove	Natural Space General State Protection Zone Zepa Zone Ramsar Important area for the Birds (IBA)	X	
Sálvora & Cortegada Islands	Nacional Park Zone Zepa Zone Ramsar Important Area for the Birds (IBA)	X	Islas Atlánticas
Corrubedo e Lagoas de Carregal e Vilán	Natural Park Ramsar	X	

At the south of the Arousa's Bay, located in 42º27´11" N – 08º51´53" W there is the RAMSAR wetland area ***Umia-Grove inter-tidal Complex*** that occupies 2,561 ha and it is the ecosystem considered as one of the richest in Galicia. The transition between the maritime and terrestrial environment occurs a gradual manner, with oscillating tidal movements on wide land surfaces, apart from the many rivers which flow into this area contributing to enrich the ecosystem with their fresh water.

The littoral or inter-tidal complex consists of several biotopes (inlets, beaches, dunes, etc.) which account for the great variety of fauna and flora. These biotopes in the Umia- O Grove inter-tidal complex create wetlands of international importance for avifauna since this is a resting area for more than 100 bird species during their emigration journeys, waders, sea crowns, herons, mallards and many more.

For this reason this inter-tidal complex has been included in the RAMSAR Convention (Official Spanish Bulletin 8-5-1990) and has been acknowledged as a Special Birds Protection Area in 1989 in accordance with the European directive 79/409 EEC regarding the conservation of wild birds. It has also been included in the Spanish Proposal of Places of European Importance in order to be accepted in the Natura Network 2000 (2001).

The Complexo Umia-Grove, LIC code ES140004, LIC surface 7,506.75 ha identifies the following habitats:

- Sand banks permanently cover by shallow water
- Marshes
- Fixed coastal dunes with herbaceous vegetation
- Shifting dunes along the shoreline with Hammophila arenaria
- Sand dunes communities
- Atlantic salt meadows (*Glauco-pucciellitalia maritimae*)
- Pasture of *Spartina*
- Mediterranean and thermo-Atlantic halophilous scrubs (*Sarcocornetea fruticosi*)
- Mediterranean tall humid grassland of the Molinio Holoschoen

The SAC includes the following fauna and flora:

- **Flora** – Rumex (*Rumex ruprestris*)
- **Fauna** – highlights the presence of more than 13,000 aquatic birds in winter. It is the wetland most important of Galicia and one of the most important of Spain. Important nesting areas for around 29 different species of aquatic birds.
    - **Birds** - Cormorant (*Phalacrocorax aristotelis*), Heron (*Egretta garzetta*, Spoonbill (*Platalea leucorodia*), Teal (*Anas crecca*), Blue duck (*Anas platyrhynchos*), Falcon (*Falco peregrinus*), Oystercatcher (*Haematopus ostralegus*), Puffin (*Puffinus puffinus mauretanicus*)
    - **Mammals** – Otter (*Lutra lutra*), Dolphin (*Tursiops truncatus*), Porpoise (*Phocoena phocoena*)
    - **Amphibians** - Frog of San Antón (*Hyla arborea)*has been signalled in the lagoon

A few kilometres away from the inter-tidal complex is the ***National Park of the Atlantic Islands***. In June 2002 the Spanish Congress of Deputies signed an agreement to create the National Land-Marine Park of the Atlantic Islands of Galicia, formed by a number of archipelagos, islands and cays, namely the Cíes, Ons, Sálvora, Nor, Vionta, Cortegada and the Malveiras. Sálvora and Vionta are located at the entry of Arousa´s Bay (42º27.9 N-9º0.8W) and Cortegada, Nor and Malveiras at the bottom of the bay at the Ulla´s river estuary The Atlantic Islands National Park of Galicia is also classifies as SAC/ ZEPA included in Natura Network 2000, which develops European Union Directives in relation to habitats and birds, with very interesting flora and fauna, and resting area for cetaceans and sea birds.

Sálvora Island classifies as National Park, (integrated in the Atlantic Island) is a Zone Zepa, Zone Ramsar and Important Area for the Birds (IBA), identifies the following habitats:

- Maerl beds (*Lithothamnion coralliodes & Phymatolithon calcareum*)
- Mussel and barnacles bed communities (*Mytilus galloprovincialis* & *Pollicipes cornucopia*)
- Sea grass beds

Cortegada Island is classified as a National Park (integrated in the Atlantic Island) with a surface of 43.8 ha. holds a Tertiary Forest of *Laurisilva.* Around the island there is a large area for clams cultivation (*V pullastra, T decussata*, R *philippinarum, C edule).* This Island has its own specific conservation features of the SAC (2002).

At the northwest slope there is another Wetland of International Importance of the Ramsar Convention since 1982 called ***Complexo de praias, dunas e lagoas de Corrubedo*** (Wetland– RAMSAR Corrubedo Dunes), 550 ha; 42º33'N 09º02'W. Natural Park, Wildlife Refuge. A major dune system with an enormous shifting dune is included in the Natura 2000 network as SAC & ZEPAs. The site includes partially enclosed sandbar lagoons, and numerous streams form an extensive marshy area giving way to a belt of pine trees. The area provides an outstanding example of dune flora and is particularly notable for several endemic species and sub-species. The site supports salt-resistant vegetation and extensive reed beds. Numerous reptiles, amphibians, and mammals are present, and the area is important for breeding, staging and wintering water birds. Human activities include tourism, agriculture, and rush harvesting. There are an information centre and bird observatory available to visitors.

Complexo litoral de Corrubedo LIC code ES 110006, LIC surface 9,264.64 ha - Habitats within site:

- Fixed coastal dunes with herbaceous vegetation
- Atlantic salt meadows (*Glauco-pucciellitalia maritimae*)
- Mediterranean tall humid grassland of the Molinio Holoschoenion
- Mediterranean and thermo-Atlantic halophilous scrubs (*Sarcocornetea fruticosi*)
- Malcolmietalia dune grass land
- Coastal lagoons
- Embryonic shifting dunes
- Shifting dunes along the shoreline with *Hammophila arenaria*
- Salicornia and other annuals colonizing mud and sand
- Annual vegetation of drift lines

And includes the following fauna and flora:

- **Flora** – Flowering plants (*Orphaloide litoralis*)
- **Birds** - *Anas platyrhynchos, Anas strepera, Anas crecca, Ardea cinerea, Ardea purpurea, Buthinus oedicnemus, Calidris alba, Calidris alpina, Limosa lapponica, Phalacrocórax carbo, Sterna hirundo*
- **Mammals** – *Lutra lutra*, *Myotis myotis*, *Rhinolophus ferrumequinum*, *Rhinolophus hipposiderus*
- **Amphibians –** *Discoglosus ieanneae*

In the Ría de Arousa there are located two maerl beds with specific conservation features. One maerl bed has been identified at the entry of the bay in Sálvora Island (42º28 N-9º0.8W) and the another at the proximity to Ría's central channel (42º33N-8º55W).

8.2.3 Conflicts/Issues

Sedimentation: mussel rafts could exert a moderate sedimentation pressure due to pseudo-faeces but also sells and other detritus from the farming techniques. This intensive culture can create organic enrichment and anoxia in sediments. Under rafts there are accumulation of faeces and decaying mussels and fouled with high levels of carbonate, organic carbon and organic matter than can impact on benthic macrofauna: benthic macrofauna can be reduced and trophic groups altered.

Visual seascape modification: mussel rafts could exerted a moderate visual impact on the seascape of the Galician bays but are generally judged as less imposing as they are generally viewed as a traditional land use. Mussel rafts are now integrated on the seascape of rural communities around the *rías* as livelihood that is currently identified with Galicia..

Disturbance: mussel rafts could be a source of disturbance associated to transport by boat and routine human presence and a certain mechanisation with seasonal incidence, but probably acceptable in terms of disturbance to wildlife or humans.

Predator control: it is unknown that mussel farming exert a potential impacts of anti-predator netting on wildlife or another predator control.

Introduction alien species: it is very improbable that pressure can affect mussel rafts culture because the unique cultivated specie is a native one. Mussel seed come from the rocks around the bays and/or long lines. The possibility to introduce alien species is at present very remote. However, even grater part of rafts cultivate mussels a reduced number of rafts placed in the same polygons are devote to cultivate oysters, locally present but non-endemic. In these specific cases there is a strict control on the seed origin.

8.2.4 Management and Mitigation Process

Spain has approved the Strategic Plan for Wetlands Convention and Wise Use 1990 in the framework of the National Strategy for the Conservation and Sustainable Use of Biological Diversity. In addition wetlands are taken into consideration as part of different sub national nature conservation policies

Mussel culture in Arousa´s Bay as well as other *rías* is intensive but does not require high energy inputs, use of feeds or chemicals. Mussel rafts have a large physical footprint that covers a large proportion of the bay.

An emphasis on environmentally friendly practices should be encouraged. Silting of the bottoms where rafts are located may induce a problem for the benthic communities located underneath. This should be solved by strong policies directed towards correct management of the fouling and silt accumulated by the hanging ropes. The enormous amount of shells produced is being disposed in a variety of industrial ways but more diversification is needed. Biotechnology may prove a useful way of finding new alternatives to fouling and the disposal of shells.

The Autonomous Government of Galicia (Xunta de Galicia) being aware of the saturation reached in many areas devoted to mussel farming, as well as the ecological problems raised by this culture has regulated this kind of exploitation being aware of the saturation reached in many areas devoted to mussel farming as well as of the ecological problems. They have restricted the size of the platform at 500 square metres, the number of ropes per raft at 500 max and the length of ropes no longer than 12 metres (depending on depth some rafts can have ropes 8 metres length). That regulation took the form of the Fisheries Act publishing in 1993 (Decreto 423/1993). In 1996 is published the Regulations to apply to marine culture in floating structures (Decreto 406/1996)

As mussels are filter-feeders, they produce large amounts of bio-excrements under the rafts, that can represent an increase in sediments about 0.5-2 cm /raft/year.

Recently the Local Fisheries Council (Xunta de Galicia) has promoted a project co-funded under the LIFE ENVIRONMENT Programme of the EU which its main objective is to develop a system for the integral management of the wastes produced by mussels cultured. The aim is to reduce the environmental impact and restore the natural heterogeneity of the marine ecosystem. This project tries to establish a system for the extraction of sediments deposited under the mussel rafts as well as a system for selective collection and transport of the waste produced during the different working tasks associated to the mussel cultivation process. This project includes also training activities in order to involve mussel producers in good working practices of waste management and preservation of ecosystems.

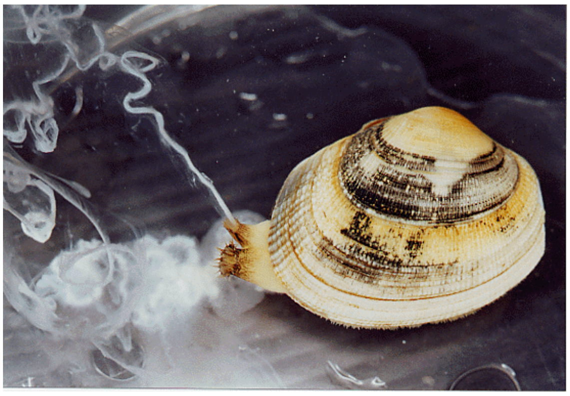
8.3 EXTENSIVE CLAM AQUACULTURE IN THE GORO LAGOON, ITALY

In the middle 1980s the lagoon of Goro or Sacca di Goro (Po River Delta, Northern Adriatic Sea, Italy) has seen the development of a flourishing economy based on the extensive aquaculture of molluscs, in particular the Manila clam (*Tapes philippinarum*) introduced in the area for the first time for aquaculture purposes in 1983 to replace the dwindling populations of the native clam (*Tapes decussatus*). The production of Manila clams grew up to more then 15,000 t per year at the beginning of the 90s, but a decline in productivity did occur in recent years and the latest production statistics (2004) indicate a production slightly above 11,000 t for a value of more then 35 million Euros (OREI, 2006). In 2003, the production of the Goro lagoon accounted for approximately 60% of the national clam production in brackish waters (or 50% of the overall national clam production).

8.3.1 Aquaculture systems

The culture of Manila clams (*Tapes philippinarum*) is an extensive aquaculture system based on the seeding of suitable coastal lagoon areas and subsequent manual harvesting.

Details of stock: *Tapes philippinarum* (Adams and Reeve, 1850) is a bivalve of Indo-Pacific origin with a shell 25-57 mm in length and commercial size of approximately 40 mm. It is a brackish waters species which burrows in sand or muddy-gravel bottoms below the mid tide level to a few meters deep, usually in quiet waters. Studies carried out in Thau lagoon (France) and Venice lagoon (Italy) revealed that the best growth period is during the phytoplankton bloom (spring and autumn) at temperatures between 10 and 20°C and the reproduction period extends from May to October (Maitre-Alain 1985). It is similar to the native calm *Tapes decussatus* (Linnaeus, 1758) from which it is distinguished by the much more pronounced decussate sculpture, the more angulated shell and the almost fused siphons.



The Manila clam was first introduced in France in 1980 and in the Venice lagoons in 1983 for experimental aquaculture, and it is now found on the coasts of the Italian regions Emilia-Romagna and Sardinia. Following introduction it rapidly spread, forming natural populations, with densities above 1,000 individuals per m² and occasionally limiting or even replacing the native *Tapes decussatus*. The reasons of its success are attributed to the favourable conditions for growth, larval dispersal and settlement (Breber, 2002).

Between 1983 and 1987 the seeds was purchased from hatcheries in the UK, Spain, France and the US. In 1987 the import of seed in Italy reached 100 million units. From 1989 onwards the seed started to be available in Italy because of the natural reproduction of the introduced individuals. Signs of natural reproduction where evident in the Goro lagoon from 1986 from where the clam spread rapidly north along the coast following the predominant currents.

Production systems: molluscan aquaculture represents the most important economic activity in the Goro lagoon, occupying more then 10 km² of the 26 km² available. The most important product, both in volume and value, is certainly the Manila clam (*Tapes philippinarum*) but the area also hosts the culture of mussels (*Mytilus galloprovincialis*) on suspended long-lines and other fisheries, including the harvesting of the oyster (*Crassostrea gigas*) on natural beds.

The Manila clam extensive aquaculture system practiced in the Goro lagoon can be defined a *"culture based fishery"* (Rossi 2000). The culture areas have well defined boundaries and are leased to fishermen cooperatives which, besides harvesting the product, undertake maintenance activities such as :

- Cleaning up the substrate
- Seeding of the areas with new recruits gathered elsewhere or produced in hatcheries
- Relocation of the product in areas most suitable for growth and reproduction

Not all the lagoon is suitable for aquaculture of Manila clams. The best areas are those which are well flushed and have the right sediment composition. The table below summarises the bio-geo-chemical conditions considered suitable for the culture of Manila clams (Rossi 2000).

Table 45: Optimal conditions for Manila clam aquaculture

Parameter	Optimal range
Depth	< 3 m
Salinity	15 - 35‰
Sediments	20 - 80% of sand
Current velocity	0.3 - 1 m/s
Dissolved Oxygen	> 40%
Chlorophyll a	<15 mg/l

The lagoon also contains nursery areas where, for natural reasons, the recruitment of new individuals is particularly high. Nursery areas are not leased but exploited by all authorised cooperatives to collect undersized individuals and seed their own culture areas.

The boundaries of the leased areas portrayed in the figure overleaf are the result of the history of the aquaculture activities in Goro. Initially, only one large Consortium (Consorzio Pescatori Goro – COPEGO) operated a single large concession. Following an anoxic crisis in 1992 which dramatically reduced profit and exacerbated internal management problems, the Consortium finally fell apart and the leased areas where subdivided in smaller parcels attributed to individual cooperatives.

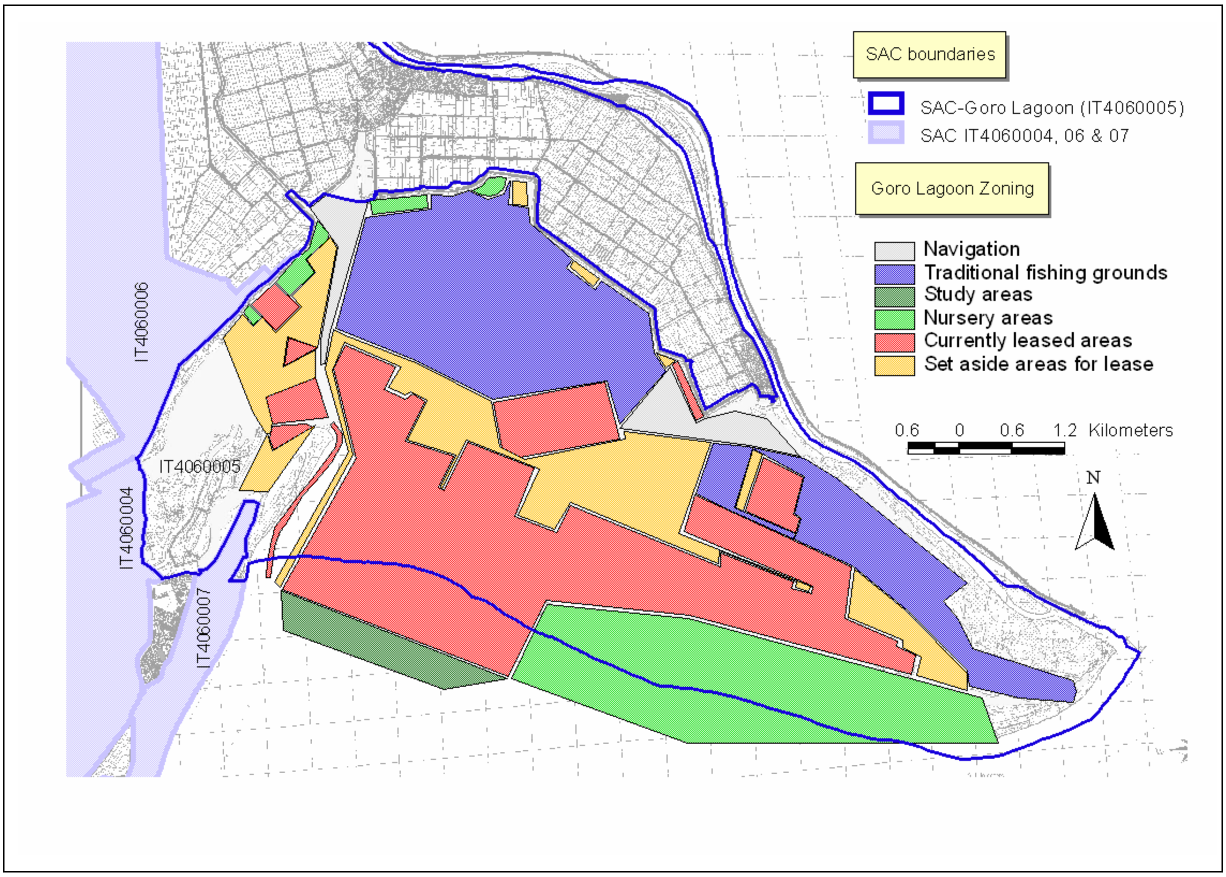
In 2005, 40 culture areas were leased for Manila clam production in the Goro lagoon for a total of almost 1,200 ha, equivalent to approximately 45% of the entire lagoon area. The leased areas are cultivated by approximately 30 firms of different nature (cooperatives, consortia, companies etc.), employing almost 1800 workers in total.

The production of Manila clam in 2004 reached 11,300 T for a total value, at current prices, of almost 40 million euros ((Malorgio *et al.*, 2006).

Table 46: Manila clam production in Goro lagoon in 2004

Production (t/year)	11,318
Productivity (t/ha/year)	9.4
Value (€/year)	37,138
Mean Price (€/Kg)	3.28

Figure 16: Zoning of the Goro lagoon for aquaculture and fisheries purposes in 2004



Source : Adapted from data provided by the Osservatorio dell'Economia Ittica della Regione Emilia Romagna (OREI)

Management practices: the largest area leased for clam culture (600 ha) is managed by the Consorzio Pescatori di Goro (Consortium of Goro Fishermen) or COPEGO, representing approximately 850 fishermen. COPEGO provides an example of how the clam culture leases are managed in the Goro lagoon.

The entire surface of the lease is divided in "fields" of different size characterised by different morphological and hydrodynamic features and, therefore, different productivity. COPEGO has defined a collaboration agreement with the Biology Department of the University of Ferrara, which undertakes a sampling programme three times a year to assess population densities in different areas. Density maps are derived and used as a basis for the management of the concession, allowing for movement of stocks from densely populated areas to other more suitable spots, preparation of the bottom for seeding and subsequent seeding (Noferini & Passerella, 2005).

The high reproductive potential of the manila clam has always guaranteed abundant quantities of natural seed, although the recruitment levels within the concession itself has fluctuated over the years. For this reason COPEGO has undertaken a seeding programme to supplement natural recruitment since 1994. Seeding is undertaken in two phases :

- Direct seeding on substrate with seed bought from a hatchery or wild seed collected at sea.
- Relocation of juveniles within the concession from high density areas to areas considered more suitable for growth.

A specially equipped boat is used for the seeding activities. While harvesting is undertaken manually with a specific tool called "rasca" which is a rake with short teeth on which a net with mesh size between 14 and 18 mm is mounted (see Figure below). This allows to leave in the substrate the smaller individuals. The "rasca" is the only tool allowed in the lagoon and no other can be used unless it is proved to cause no harm to benthic communities.

Figure 17: Rasca (left) and a group of fishermen during harvesting (right)

Source : www.federcoopesca.it

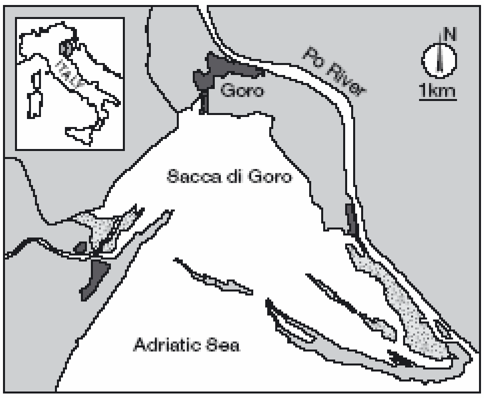
Over the years fishermen have envisaged new tools in an effort to make harvesting physically less demanding. The only other tools which have been allowed are :

- *Hydraulic rasca*: is similar to the traditional "rasca" except for a series of pipes attached to the rake which direct high pressure water into the sediment making collection easier.
- *Boat harvesting*: involves the use of conveyor belts from a small boat. The belt is positioned with one end on the substrate allowing for the removal of the first layers of sediment. This method is currently allowed only to clean up the substrate but not for harvesting.

COPEGO also prescribes the allowed number of fishermen per day and the allowable catch per fishermen per day on the basis of the market demand. Following harvesting, calms are deposited in tanks (500 cubic meters available in total to COPEGO members) with a controlled flux of depurated sea water for 12 hours to allow for cleansing and shedding of all bacterial residues. The product undergoes veterinary control and is packaged alive.

8.3.2 Surrounding environment and conservation interests

General description of surrounding environment: the Sacca di Goro lagoon (44°47'- 4°50' N, 12°15'-12°20' E) is the southernmost lagoon in the Po Delta Region, Northern Adriatic Sea. Its covers an area of approximately 26 square Km with an average depth of 1.5 m. The lagoon is part of the largest river delta in Italy including some of the best preserved fresh and salt water wetland areas in the country.



The Goro lagoon is delimited by the mouth of two branches of the Po river : the Po of Volano and the Po of Goro. The lagoon is partially isolated from the sea by two sand tongues and communicates with the sea only through a large mouth at its south-western side. The lagoon is of relatively recent formation (18th century) and the sand tongues have slowly accreted over the last 50 years. The tongues are constituted of mobile sand dunes colonised by halophytes (*Spartina maritime, Salicornia veneta etc.*) and low bushes of tamarisk (*Tamarix sp.*) on the inner side.

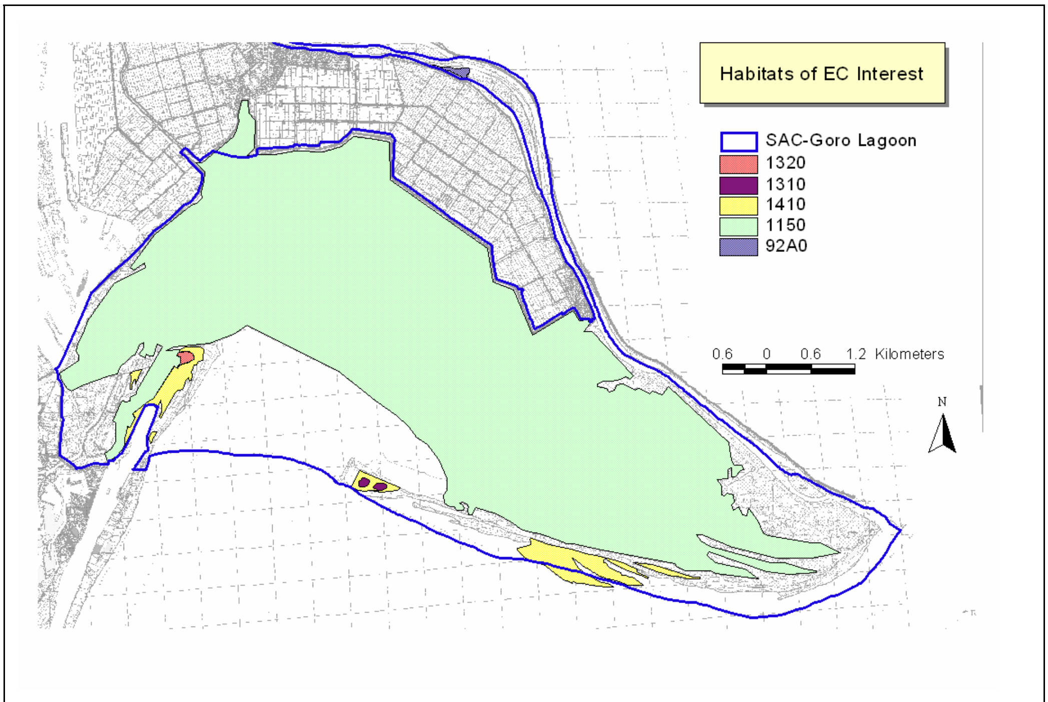
The lagoon is highly eutrophic due to large nutrient inputs of human origin reaching the lagoon through the Po di Volano. As a consequence, in spring and summer the lagoon undergoes intense macro-algal blooms, mainly due to the green algae *Ulva rigida*, with average biomasses of 3-4 Kg per square meter (Viaroli *et al.* 2001). This often results in anoxic conditions in the lagoon and die-offs of benthic communities with considerable economic damage for aquaculture activities. In the 90s, some efforts have been made to improve the water circulation in the lagoon by means of hydraulic engineering interventions (channel excavation, etc.) but the results have not been encouraging and the problems of eutrophication persist.

Conservation interests: the Goro lagoon is completely included in a proposed SAC and SPA called *"Sacca di Goro, Po di Goro, Valle Dindona, Foce del Po di Volano"* (IT4060005). It should be noted that the same SAC and SPA also includes the last stretch of the Po di Goro river for approximately 20 Km, therefore covering contiguous fresh and brackish water bodies of great conservation interest. In addition, the Goro lagoon is completely within the boundaries of the Regional Park of the Po Delta (Region Emilia-Romagna) which includes 11 areas protected under the Ramsar Convention. Of these, the coastal wetland called *"Valle di Gorino e territori limitrofi"* is immediately inland from the Goro lagoon. The SAC is also adjacent to 5 other Natura 2000 sites (IT4060004, IT4060006 IT4060007 and IT40600015) and in total the Regional Park covers 17 SACs and 14 SPAs. Given its historical role of cultural and economic crossroads between West and East, the Po Delta has been granted protection by UNESCO in 1999.

The SAC of the Goro Lagoon covers 15 habitats of community interest representing 93% of the site surface. Following the classification of habitats defined in the *Interpretation Manual of European Union Habitats* (EC, 2003), the most important ones are (see Figure below) :

- Coastal Lagoons (priority habitat) - Code 1150
- *Salicornia* and other annuals colonising mud and sand - Code 1310
- Spartina swards (*Spartinion maritimae*) - Code 1320
- Mediterranean salt meadows (*Juncetalia maritimi*) - Code 1410
- *Salix alba* and *Populus alba* galleries - Code 92A0

Figure 18: Habitats of Community Interest present in the Goro lagoon



The SAC of the Goro Lagoon covers 15 habitats of community interest representing 93% of the site surface. For what concerns species :

- **Flora** : many species considered rare or really rare and threatened have been recorded in the lagoon (*Leucojum aestivum, Plantago cornuti, Trapa natans, Erianthus ravennae, Typha laxmannii, Triglochin maritimum, Bassia hirsuta, Spartina maritima, Oenanthe lachenalii*).
- **Birds** : approximately 30 species of community interest are regularly present at the site as it represents an important nesting and feeding ground for most waterfowl. Important nesting areas for the egrets *Ardea purpurea* and *Ardeola ralloides* are present respectively in the reeds at the mouth of the Po of Goro and along the Po of Goro floodplain.
- **Reptiles** : the common sea turtle *Caretta caretta* has been signalled in the lagoon
- **Amphibians** : the crested triton *Triturus carnifex* has been signalled in the lagoon
- **Fish** : 11 species of community interest are present at the site. In particular, the final section of the Po river is of vital importance for the survival of the sturgeons *Acipenser sturio* and *Acipenser naccari* (endemic), both seriously threatened with extinction.

8.3.3 Conflicts/Issues

Sedimentation : potential impacts deriving from clam culture in lagoon areas refer primarily on the direct effects of the use of the harvesting tools (i.e. rasca and its variants) and its ecological consequences (Pranovi *et al.*, 1998). Potential negative effects linked to sedimentation include :

- The sediment re-suspended by the tool is partially washed away at sea causing a net loss of sediment to the lagoon
- Re-suspended sediments reduces light penetration and potentially limits the growth of macro-algae and marine plants

Change in bio-geochemistry : high densities of clams in the substrate seem to increase the organic content of the sediment (due to the filtering activity of the bivalves) contributing to the formation of hydrogen sulphide (H_2S) which effect negatively all benthic organisms (Sorokin *et al.*, 1999). In addition, high clam densities like those observed in some areas of Sacca di Goro (in some cases exceeding 2000 individuals per m²), have been shown to have a detrimental effect on oxygen availability in the water column effecting ecosystem productivity (Bartoli *et al.* 2001).

Change in coastal processes : in general, the Goro lagoon and its delimiting sand banks are young and highly mobile structures on which the effects of human intervention are difficult to distinguish from natural fluctuations. As mentioned above, the Goro lagoon and the Po of Volano and Goro have undergone several engineering interventions to improve water circulation in the lagoon and reduce the occurrence of anoxic conditions which cause great economic damage because of the die-offs of clams. These interventions do not seem to have had any visible effect on the costal processes of the area (Mistri *et al.*, 2002).

There is also a suggestion that the groove on the substrate left by the tool used for harvesting clams may increase erosion processes locally (Casale & Giovanardi, 1999).

Disturbance: given the presence of waterfowl of conservation interest in the area, aquaculture activities in the lagoon (motor boats travelling to and from the leased areas) might negatively effect the feeding or nesting behaviour of some bird species (Costa, 1997).

In addition, given the particular nature of the aquaculture activity, the use of the harvesting tool (rasca) seems to have the potential to cause direct or indirect disturbance benthic communities (Casale & Giovanardi, 1999) :

- Tool penetration in the sediment causes the destruction of holes dug by bottom dwellers like fishes of the family *Gobidae* which are characteristic of the lagoon area
- The groves are eventually re-colonised by opportunistic species with a shorter life-cycle with a general tendency towards a reduction of diversity in the short term (the original benthic community would be eventually re-established in the long term, provided it is given sufficient time)
- Amongst the benthic species, marine plants typical of the Mediterranean such as *Zostera marina, Z. noltii* and *Cymodocea nodosa* are physically removed by the harvesting tool and take a considerable time to grow back. In addition, removal of these marine plants may negatively effect other species which depend on it like the garfish (*Belone belone*) and the sand smelt (*Atherina boyeri*) which lay their eggs also on the leaves of these plants (Giovanardi & Pranovi, 1999).

Introduction of Alien Species : *Tapes philippinarum* itself is an alien species of indo-pacific origin which has almost entirely replaced the local clam *Tapes decussatus* whose population was already dwindling before the introduction. Other species have been introduced (intentionally or accidentally) in relation to aquaculture activities. Amongst these the case of the bivalve *Musculista senhousia* is worth mentioning. *Masculista* has been present in the Goro lagoon since 1995 and was probably introduced accidentally along with oysters or clams of French or Japanese origin used for aquaculture purposes. The species is highly opportunistic and thrives in nutrient-rich environments growing fast and showing high fecundity. When the density is sufficient (they can reach densities of over 100 individual per m^2) the byssus produced bye each individual forms a unique solid layer on the bottom surface which includes sediment, shells and algae. This "carpet" covers the bottom and isolates the underlying sediment from the water column causing anoxic conditions and effecting the benthic communities. These carpets may have an effect on Manila clam recruitment but there seems to be no direct impact on Manila clam mortality, therefore clam culture activities do not seem to be negatively effected if not for the difficulty of harvesting in areas where the carpet has formed (AA.VV., 2005; Mistri *et al.*, 2004).

8.3.4 Management and Mitigation Process

The aquaculture activities in the Goro lagoon are extensive, therefore do not require high energy inputs, use of feeds or chemicals. On the other hand, culture covers a very large surface (12 km^2) making the physical footprint of clam aquaculture very large.

As mentioned above, the culture areas are carefully controlled and managed by the fishermen the cooperatives and the zoning of the lagoon agreed by all stakeholders guarantees minimisation of conflicts in the area.

Nevertheless, the following mitigation measures have recently been suggested to further reduce the impacts (Pagnoni G. A., 2003):

1. Continue with the use of the traditional harvesting tool (rasca) and do not start using mechanical tools (e.g. turbo-blowers used elsewhere in the northern Adriatic Sea) which are more efficient but much more damaging for the substrate and the benthic communities.

2. Aquaculture activities should be suspended in area of particular conservation interest. In particular:
   - Harvesting should be prohibited in areas where the threatened macrophyte *Ruppia spiralis* occupies the bottom of the lagoon.
   - Access to the sand banks between April and June should be either limited (to professional harvesters) or prohibited (to amateur harvesters and tourists) because of the nesting of seagulls and sterns of various species of conservation interest.
   - Given the geo-morphological and ecological importance of the sand banks delimiting the lagoon, no equipment should be left or works undertaken on the banks and harvesting activities should remain within a certain distance (8 m).
   - The introduction of new species of molluscs or other species for aquaculture purposes should be prohibited.
   - Limits to motorboats speed and horsepower should be set because the waves produced by speeding boats may damage sand and river banks causing erosion.
   - Transit of motorboats should be prohibited altogether in some areas close to important bird nesting sites.

There is no specific SAC or SPA management plan at the moment. Nevertheless, given the economic importance of aquaculture activities in Goro and the need to respect environmental regulation set by the EC Habitats Directive in the area, the Regional Park of the Po Delta and the Region Emilia-Romagna have recently (2004) approved a regulation to define the Appropriate Assessment procedures required before a lease for clam aquaculture purposes in the lagoon can be approved and granted. Annex A to this regulation defines the technical criteria on which the appropriate assessment should focus :

1. Only calm (*Tapes philippinarum* or *Tapes decussatus* is allowed);
2. The aquaculture activity has to include the seeding of recruits, growth control, maintenance of the area and clean up of invasive species or macro-algae;
3. Harvest has to be planned on the basis of the market demand and density control on clam banks;
4. Seed needs to be of local origin or come from other productive areas and hatcheries for which origin and sanitary conditions can be demonstrated;
5. Product control should be achieved by sampling to verify growth;
6. The productivity of the area has to be regularly tested through biological sampling;
7. Product may be harvested only manually with the *rasca*;
8. Product must be washed in the same water in which it is harvested and residues of the cleansing process have to be treated according to a specific protocol approved by the Region Emilia-Romagna;
9. Leased areas need to be marked at their corners by wooden poles (40 cm in diameter and 2 m high above mean sea level) on which lease identification information must be displayed. Other poles of smaller size can be used to outline the edges of the leased area.
10. Regularly registered motorboats have to be used to access to the leased areas;
11. The product can be landed only in authorised areas;
12. If the leased area is close to sand banks, all harvesting activities must remain within 8 m of the edge of the banks or other existing vegetation.

8.4 SEA BASS AND SEA BREAM FARMING IN THE SARONIKOS GULF, GREECE

This case study examines the typical Mediterranean cage farm for sea bream and sea bass. The two farms examined (Farm I and Farm II) are located in the SE Saronikos Gulf, in the (NUTS 2) region of Sterea Ellada in Greece.

8.4.1 Aquaculture systems

Details of stock: the species cultured in the fish farms under investigation are: sea bream (*Sparus aurata*) and sea bass (*Dicentrarchus labrax*). The broodstock comes from Spain (as for the majority of broodstock used in fish farms in Greece) as well as from France. Both farms are provided themselves with fry from the hatchery of Farm I, which is placed in Sitia, Crete.

Production Systems and management practices: both farms examined use rectangular and square cages. Farm I (which is the biggest one) produces 400 tonnes of sea bream and sea bass annually in 18 rectangular cages (6 ones of dimension 15x15m and 12 ones of 12x12m) and 9 square cages (of 60m diameter). There are no installations on land. 640 tonnes of feed are provided to the fish annually. Fry is fed with Trouvit feed and larger fish with Biomar feed. 3-4 workers are employed on a permanent basis. Feed is given by hand to the rectangular cages and mechanically to the square ones. Feed is transported to the cages by boat. Fish are farmed on a one-year-plus production cycle.

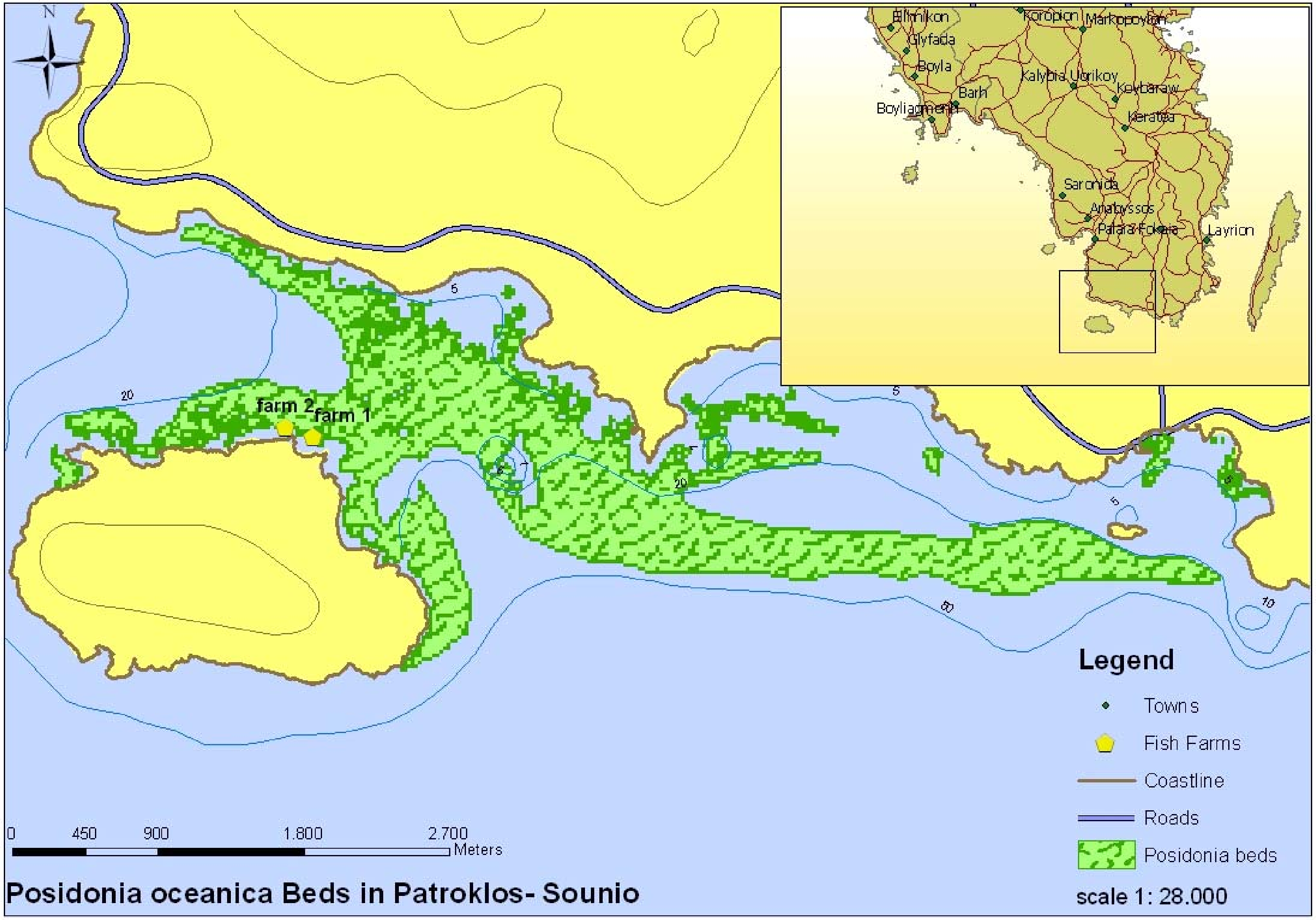
8.4.2 Surrounding environment and conservation interests

General description of surrounding environment: the area under investigation is situated at the SE of Saronikos Gulf which is a semi-enclosed area of the SW Aegean Sea, in fact an extension of the South Aegean. At the head of the eastern part of this gulf lies the Athens metropolitan complex. Saronikos Gulf constitutes a complex ecosystem due to the topographical and hydrological differentiation of the area, as well as its trophic character. In the inner part of the main Saronikos Gulf depth does not exceed 90 m and a mesotrophic character is attributed to this sub-area, mainly due to the discharge of domestic and industrial effluents from the city of Athens. The outer part of the gulf, positioned on the continental shelf (maximum depth 240 m), is in large communication with the Aegean Sea, which provides source water to Saronikos Gulf. Salinity in Saronikos Gulf usually ranges between 37.5 and 38.5 psu. Existing data for the unpolluted areas of the gulf have demonstrated a defined seasonality pattern on the annual cycle of plankton (Pagou, 1994; Siokou-Frangou, 1996) controlled by the phosphorus and nitrogen availability (Ignatiades, 1969).

The Saronikos Gulf is one of the most studied Greek gulfs; there is a considerable amount of literature concerning the effects of sewage on nutrients and phytoplankton (Becacos-Kontos and Friligos, 1973; Friligos, 1985), phytoplankton annual cycles, species composition and distribution (Ignatiades and Becacos-Kontos, 1970; Ignatiades, 1979, 1981, 1984; Karydis and Moschopoulou, 1982; Karydis *et al.*, 1983), primary production (Becacos-Kontos, 1967, 1981; Ignatiades, 1977, 1990; Ignatiades *et al.*, 1987) and zooplankton ecology and systematics (Yannopoulos, 1976; Moraitou-Apostolopoulou, 1976, 1981; Moraitou-Apostolopoulou and Ignatiades, 1980; Siokou-Frangou *et al.*, 1998).

The very area where these farms are located (see Figure overleaf) is probably one of the most oligotrophic areas of Saronikos Gulf. It is more than 30 km away from the highly developed coasts of Attiki and also more than 5 km away from any municipality or hotel complex in the area. Furthermore, the fish farms use an area between the coast of Attiki and a small island (Patroklos) so that the area is continuously flushed by a strong current and at the same time they are very well protected against the predominant winds of the area.

Figure 19: Location of the two cage farms in respect to the *Posidonia* Seagrass Meadows



Conservation interests: in the area under investigation there are extended meadows of *Posidonia oceanica*. The water depth is 16 m and the sediment is carbonate sand. The *Posidonia oceanica* meadows are situated at a distance >15m from the edge of the cages.

The seagrass *Posidonia oceanica*, an endemic species of great ecological importance for the Mediterranean Sea, greatly suffers from aquaculture activities. *P. oceanica* is the dominant seagrass species in the Mediterranean, covering 2.5-5.0 10^{10} m^2 of the Mediterranean coastal zone, extending from 0.3 to 45 meters depth (Bethoux and Copin-Monteagut, 1986; Pasqualini *et al.*, 1998). *P. oceanica* is a slow-growing species (Marbà and Duarte, 1998), with sparse reproductive episodes, requiring centuries to colonise coastal areas (Duarte, 1995; Marbà *et al.*, 2002). *P. oceanica* plays major ecological roles on the coastal zone (e.g. prevents coastal erosion, increases coastal biodiversity, oxygenates the water and sediments, increases water transparency, is a carbon sink). Despite *P. oceanica* meadows have persisted over millennia (Mateo *et al.*, 1997), they are highly vulnerable to marine aquaculture activities as reflected by the large-scale losses of *P. oceanica* reported nearby fish farms (e.g. Delgado *et al.*, 1997; Ruiz *et al.*, 2001) even after cessation of farming activities (Delgado *et al.*, 1999). The decline of *P. oceanica* meadows nearby to fish farms has been attributed primarily to the deterioration of sediment quality (Holmer and Nielsen, 1997), reflected in symptoms such as anoxia, high organic matter and sulphide concentrations, or high sulphate reduction rates, processes and conditions detrimental for seagrass survival and growth (e.g. Terrados *et al.*, 1999, Holmer and Nielsen, 1997). In addition, changes of epiphytic density and/or an enhancement of grazing pressure (Ruiz *et al.*, 2001) in response to environmental nutrient enrichment derived from fish farm activities may enhance seagrass loss.

8.4.3 Conflicts/Issues

Sedimentation: data from sediment traps deployed at this site (Karakassis & Tsapakis unpublished data) have shown that the sedimentation at these sites is extremely low in comparison to other Mediterranean sites. The strong currents in this area and the coarse sediment at the farm sites were identified (Karakassis *et al* 2000) as the reason for the relatively low effects on marine macrofauna. However, investigation of *Posidonia oceanica* mortality rates at these sites in the framework of the EU project MedVeg (Holmer *et al.* 2005) have shown that even these levels of sedimentation have caused considerable degradation of *Posidonia* meadows downstream at distances >300m from the farm. Throughout the year the sediment redox was positive Eh and the TOC concentrations low (Karakassis *et al* 2000).

Change in bio-geochemistry: the effects on geochemical variables of the water column such as nutrients POC, PON and pigments were also difficult to detect (Pitta *et al* 1999) and even more so in the case of various plankton groups examined. This was partly due to diel changes (Pitta *et al.* 2006 in press) resulting from a combination of food supply patterns and hydrodynamic processes. On the other hand bioassays with dialysis bags (Dalsgaard & Krause-Jensen in press) have shown than there are conspicuous changes in primary productivity which are detectable at distances at least 200m from the farms. Further experiments with bioassays (Karakassis *et al.* in preparation) have shown that microzooplankton grazing plays a very important role by clearing phytoplankton and transferring the energy to higher trophic levels of the food web.

Change in coastal processes: not relevant

Visual land and seascape modification: despite the proximity to Athens, the area is not well developed. It is close to a small island and the farms are not easily observable from the continental part of the shore. However, there have been conflicts with owners of land in the area who had intentions for developing tourist infrastructure in that area. This conflict had been presented by a Greek TV programme a few years ago.

Disturbance: not relevant regarding wild life.

Predator control: no predator control systems are used by the farms located in this area. In fact no large predators such as marine mammals or sea turtles are found there and the marine birds in the area are not a problem.

Chemical use: according to the fish farmers located in this area, they had very low incidence of disease or parasites and therefore the use of antibiotics or other disinfectants is very scarce at this particular site. However they do use antifouling paints. No record of quantities is kept nor has the effects of these agents been studied at this area

Pathogen transmission: low occurrence of disease (as in 7 above) due to excellent hydrographic conditions and high flushing rates.

Inter-breeding with wild organisms: there is no system in Greece for registering escapees and therefore data on this issue are not available. The sites used for aquaculture in this particular area are characterised by continuous and high velocity currents but the wave height is usually rather small and therefore the farms have not experienced large destruction events. Nevertheless, escaping of fish through holes on nets or during handling can not be excluded.

Introduction of alien species: there is no record of introduced species in that area. The decline of *Posidonia* provides space for colonisation by *Caulerpa* species among which *C. racemosa* is probably the most successful (Piazzi *et al* 2005). This species has not been found in Sounion despite the fact that there is a noticeable regression of the *Posidonia* meadow in the area.

Indirect pressures on the ecosystem: the accumulation of wild fish beneath the fish farms has probably stimulated intense fishing in the vicinity of the farm. The IMBC team (I. Karakassis personal communication) had deployed current meters for three months at a very short distance from the fish farms (ca 30m) and these had been trawled up twice during this period.

8.4.4 Management and Mitigation Process

No mitigation measures have been used since there was no problem envisaged: the effects on macrobenthos and plankton are almost negligible. The major environmental problem (regression of seagrass meadows) was identified through a research project, which was completed 15 months ago. No monitoring action has been used to assess the state of the environment and no baseline studies had been undertaken before submitting the EIS.

9 OUTLINE CLASSIFICATION OF AQUACULTURE SYSTEMS IN ENVIRONMENTALLY SENSITIVE AREAS

Various methods of classifying different forms of aquaculture have been used in the past. The purpose behind these classification systems have usually been to assist regulators and researchers segregate different systems either according to *culture method* or according to the *level of production intensity* (see Shang, 1981), or the combination of the two. This approach is useful in that it is straightforward and relatively easy to classify systems - for this reason, the report to this point has been based on this traditional approach. However a knowledge of the production system does not immediately identify the potential impact that system might have on sensitive environments - this therefore section explores whether there might be an alternative classification system that will allow planners to *categorise systems according to their ecological risk*.

9.1 TRADITIONAL CLASSIFICATION OF AQUACULTURE

The different production methods appropriate to European coastal aquaculture have been explored early on in the report (see page 10) but it is worth briefly reviewing the concept of production intensity as it has relevance to a system's *potential* environmental impact. From aquaculture research, Coche (1982) and Muir (1995) present uni-dimensional guides for classification of different aquaculture systems, using production intensity. However most measures of production intensity come from an economic perspective and argues that intensity is the use of variable inputs (e.g. fry, feeds, fertilizers) in relation to land. However, as with economic measures of partial productivity, the inputs can be substituted for one another to some extent, so that measuring one input cannot be totally satisfactory and if is more usually to employ a multivariate approach to classification that allows us to look at the particular sets of combinations of inputs that currently define production practices.

There are four widely recognised levels of production intensity, these being:

Level	Stock density	Feed inputs	Other inputs	Water exchange	Land footprint
Hyper-intensive	>100 kg/m³	100% artificial feeds	Chemotherapeutants as required	Recirculation so minimal net use.	Minimal, usually under cover
Intensive	10-100 kg/m³	100% artificial feeds	Chemotherapeutants as required	High, using pumped seawater or sea cages	Low: cage sites, tanks or man-made ponds.
Semi-extensive	1-10 kg/m³	<100% feeds.	Inorganic fertilisers & Chemotherapeutants as required	Medium, using pumped seawater or tidal exchange	Medium: man-made ponds
Extensive	>1 kg/m³	No feeding	Organic fertilisers only.	Low, occasional tidal exchange.	Medium to high: man-made and natural pond / lagoon areas

This system of classification is useful in the planning of aquaculture in coastal areas in that it can be related to the environmental carrying capacity of potential development areas and can therefore be used for broad-scale zoning.

However there is an ever-growing number of tools for the planning of aquaculture development in coastal areas and these have grown beyond simple spatial zoning and include approaches such as:

- Participatory socio-economic appraisal: facilitate the exchange of information and opinion between stakeholders, researchers and planners, and in particular to synthesise information about resource use, exchange and interactions.
- Remote sensing and GIS zoning: useful but limited tool in gathering physical parameters over large areas and classifying them to natural features and land-use types.
- Carrying capacity estimation: define acceptable limits of environmental change; define and quantify the relationship between aquaculture and measurement variables; and calculate the maximum rate or level of activity which will not breach acceptable limits.
- Risk assessment: calculation of risk and uncertainty of uncontrollable externalities of weather, disease and world markets.
- Environmental impact assessment: site-specific – and cumulative assessment – of the environmental impact of planned aquaculture activities on the receiving environment in order to permit, refine siting and operational activities and monitor effects.

In reality, a mixture of these approaches will be used, depending upon the scale of the planning exercise as well as the particular conditions involved.

9.2 OBJECTIVES OF 'ECOLOGICAL' CLASSIFICATION

The project ToR requests "a systematic classification of fish and shellfish farms in relation to their likely or proven impact on the environment". Such 'ecological classification' has been attempted before, where analysts have tried to widen the traditionally rather narrow perspective of aquaculture classification to include wider resource input/output, cost/benefit and socio-economic issues. However the broadening of the classification horizon brings in a series of new matters, in that aquaculture ecosystem relationships are complex systems that are (i) hierarchal in nature, (ii) have different properties and dynamics occurring at different scales of organisation; and (iii) have inherent uncertainties that require ecologists to incorporate and build in uncertainty (Costa-Pierce, 2003). Furthermore aquaculture is not a 'uniform' industry that is easy to classify, codify or regulate. It is therefore very important to define the structure, functions and hierarchical placement of an aquaculture system before addressing its environmental linkages and impacts. If successful, an 'ecological classification' can permit scientists to inform decision-makers about the ecological options, the tradeoffs and uncertainties involved, and the various strategy options for influencing what happens.

In the context of this project, the objective of developing this wider classification system is to allow planners and other decision-makers to (a) characterise aquaculture activity according to their potential impact upon sensitive environments, (b) to trigger a series of management options appropriate to the size and scale of an operation; and (c) to provide planners with thresholds for development of certain aquaculture types and density.

9.3 PROPOSED CLASSIFICATION OF AQUACULTURE IN SENSITIVE AREAS

As described above, the challenge is to develop a classification system that can be generically applied across European aquaculture – both finfish and shellfish – which allows planners and managers to categorise aquaculture according to its potential impact on sensitive environments.

As described in the previous section, an analysis of the key variables and their determinants indicates that a simple classification can be developed around the following points:

- The degree of isolation of the culture system from the natural environment;
- The production intensity, hence the level of resource use and effluent streams; and
- The health, resilience and dynamism of the receiving environment to stressors.

A preliminary classification has been developed overleaf that reflects the first two of these points. The third point is site-specific so can only be used in a second stage of analysis one the preliminary classification has been applied. This new classification is based on the openness of the system to the external environment and therefore indicates its ability to impact sensitive areas outside of the immediate system. The classification also takes the traditional, production-intensity based approach (see page 210) as a secondary classification level.

Table 47: Proposed Ecologocal Classification of Aquacuaculture

Class	Intensity	Examples
A. Open aquaculture systems	Intensive	Suspended shellfish culture
	Semi-intensive	Bottom & rack culture of shellfish
	Solar	Relaying of shellfish & finfish ranching
B. Partially-open aquaculture systems	Intensive	Cage finfish culture
	Semi-intensive	Land-based pond culture of finfish
	Solar	Small-scale pond farms
C. Closed aquaculture systems	Intensive	Land-based recirculation systems

9.3.1 A. Open Aquaculture Systems

Open aquaculture systems are those without any form of physical containment and therefore have direct connectivity with the external environment. Three forms of open systems are represented in European aquaculture:

Intensive: highly productive (25-100 kg/m^3) shellfish culture system utilising raft-suspended ropes placed in well flushed water bodies. Relatively small footprint and relying essentially on external resources. Attractive to terrestrial and avian predators but relatively easy to protect.

Semi-intensive: low to moderately productive (1-10kg/m^3) systems in inter-tidal and sub-tidal areas, often enclosed or semi-enclosed lagoons. Utilises natural productivity boosted by fertilisers and supplementary feeds. Diffuse effluents but may become an issue in enclosed waterbodies. System entirely open, so culture species usually sessile although can spread if a broadcast spawner. Location in the inter-tidal and sub-tidal zones makes attractive to avian predators.

Solar: extensive low yields(<1 kg/m^3) based entirely on natural productivity. Usually involves the relaying or stocking of juveniles in open areas to boost natural productivity. No supplementary feeding nor fertilisation. Minimal management and no effluents produced.

Table 48: Environmental Pressures of Aquaculture Related to an Ecological Classification Scheme

Pressure \ System Classification	Open Aquaculture Systems			Partially-open Aquaculture Systems			Closed Aquaculture Systems
	Intensive	Semi-intensive	Solar	Intensive	Semi-intensive	Solar	
Sedimentation	Moderate	Low	Low	Moderate	Moderate	Low	Negligible
Change in bio-geochemistry	Moderate	Negligible	Low	High	Moderate	Low	Low
Change in coastal processes	Negligible	Negligible	Negligible	Negligible	Moderate	Low	Negligible
Infrastructure impacts	Negligible	Low	Low	Negligible	High	Negligible	High
Visual land & seascape modification	Moderate	Moderate	Negligible	Moderate	High	Negligible	Moderate
Disturbance	Moderate	Moderate	Moderate	Moderate	High	Low	Low
Predator control	Low	Negligible	Moderate	High	Moderate	Low	Low
Chemical use	Negligible	Negligible	Negligible	High	Moderate	Low	Moderate
Pathogen transmission	Negligible	Low	Low	Moderate	Moderate	Negligible	Moderate
Inter-breeding with wild organisms	Negligible	Negligible	Negligible	Moderate	Low	Moderate	Low
Introduction of alien species	Low	Moderate	Moderate	Moderate	Low	Moderate	Low

Level of pressure exerted: High | Moderate | Low | Negligible | ? Uncertain

The pressures exerted by the different aquaculture system classes ('Open', 'Partially-open' and 'Closed') are demonstrated in the figure overleaf. Open systems, even intensive examples, are characterised by their low levels of inputs in terms of feeds or chemotherapeutants. As a result they tend to have dilute effluents, although intensive raft mussel culture may be a significant source of suspended solids and may alter primary productivity in their vicinity. Open systems tend to have little habitat alteration from supporting infrastructure, and because they largely use local broodstock or juveniles, have a low level of pathogen transmission or scope for interbreeding with wild stocks. However, due to the low level of productivity of most open systems, they tend to have a large footprint that often utilises low-lying habitats of considerable ecological functional importance and due to the relatively high numbers of staff per unit output, have a high potential for disturbance. A number of extensive open systems may wish to use fast-growing culture species that might be absent from the local environment.

9.3.2 B. Partially-open Aquaculture Systems

Partially-open systems are usually located in existing waterbodies or in low-lying areas. They are closely linked to, and dependent upon, the surrounding environment but are usually decoupled through a physical barrier such as a cage or pen net or by pond dykes. This barrier is intended to prevent the interchange of stock yet allows the exchange of water and the discharge of effluents into the external environment.

As with open systems, there are three intensity-based sub-classes:

Intensive: highly productive (25-100 kg/m^3) system utilising either through-flow of abstracted water or cage systems placed in well flushed water bodies. Relatively small footprint and relying essentially on external resources. Stocks contained within system but partially open to external environment (screens / nets) so vulnerable to containment failure. Some on-site effluent treatment possible for land-based farms but generally depends upon a high assimilative capacity of the receiving environment. Attractive to terrestrial and avian predators but relatively easy to protect.

Semi-intensive: moderately productive (1-25 kg/m^3) system, usually using shallow ponds constructed in low-lying areas with either pumped or tidal recharge capacity. Sites often consist of groups of small-holdings or larger individual farms. Utilises natural productivity boosted by fertilisers and supplementary feeds.

Diffuse and intermittent effluents but may become an issue in enclosed waterbodies. Stock loss possible through containment failure and inadequate screening. Shallow ponds and location on low-lying supra-littoral or inter-tidal zone makes attractive to terrestrial and avian predators but difficult to protect.

Solar: extensive low yields(<1 kg/m^3) based entirely on natural productivity. Established in natural depressions in marshes, ditches and empoldered lagoons, using tidal or seasonal inundation with minimal hydrological intervention. No supplementary feeding although may use fertilisers to boost natural productivity. Endemic stock introduced, usually from adjacent capture fishery. Minimal management, although some pesticides may be used to minimise by-catch. Little or no effluents produced.

As can be seen from the table on the previous page, partially-open systems such as cage farms or land-based pond farms exert higher environmental pressures than either open or closed systems. This reflects a number of attributes of such systems:

- Both intensive and semi-intensive partially-open systems produce relatively high levels of waste. In the case of cages, sites depend upon a high degree of water exchange and large waterbodies with appropriate assimilative capacity to disperse and absorb this waste. Land-based farms will have higher flushing times but have greater opportunities to trap and eliminate both suspended solids and nutrients.
- Both cage and land-based systems are likely to be positioned in areas of high natural productivity and will provide a focus of avian, terrestrial and aquatic predators. As such, there will be inevitable conflicts, with both proactive approaches (e.g. acoustic deterrents) and active measures (e.g. extermination or trapping) having a potential impact on local populations.
- Both cages and land-based farms tend to be concentrated in a particular location. Cage farms have little permanent infrastructure, although their mooring anchors and lines may pose a threat to physically sensitive habitats such as polychaete reefs and seagrass beds. Land-based farms may result in the extensive modification of low-lying coastal areas with consequential loss of environmental services and alteration to the physical landscape.
- Although partially-open systems have a degree of stock containment, these are not infallible and the risk of stock loss to the external environment is ever present. As these productive systems often use alien species or broodstock that differ genetically from local populations, there is potential for the transmission of pathogens to and from stock, inter-breeding with wild stocks and the possible establishment of alien species in the local environment with consequences for ecological function and productivity.

9.3.3 C. Closed Aquaculture Systems

Closed systems are usually intensive aquaculture units that recirculate the bulk of its water supply, thus allowing a high degree of isolation from the external environment. These systems are extremely productive (>100 kg/m^3), usually land-based with a minimal footprint and relying entirely on external resources. Site selection therefore reflects location of these external resources rather than *in situ* land characteristics.

As the table on page 213 shows, these systems have little impact on adjacent sensitive environments. Due to their comparative self-sufficiency, they do not need to be sited to utilise natural features or productivity and can therefore generally avoid being site in or even adjacent to sensitive areas. Therefore, although the facilities are usually highly engineered, they are unlikely to infrastructure impacts.

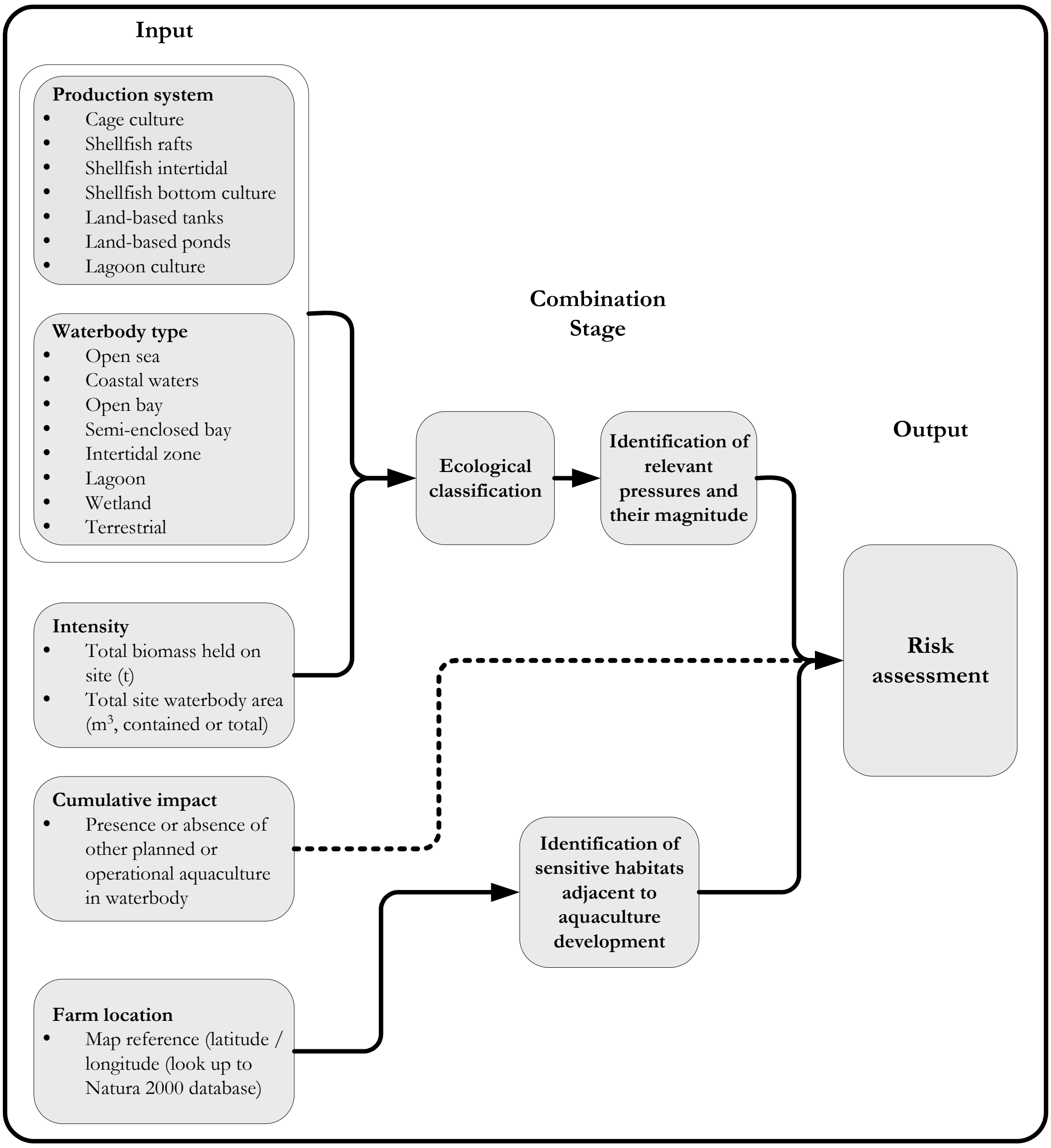
Due to their intensive nature, closed systems have high levels of inputs. However these are highly controlled and optimised for the culture system and species. Combined with filtration and waste recovery systems, the external environmental impact of the farm can be minimised. Closed systems are often used to manipulate the environment and in order to raise high value species under totally artificial conditions – as a result a high proportion use exotic species such as barramundi and tilapia – but containment is usually very robust and there is little chance of successful stock escapes.

9.4 USE OF AN ECOLOGICAL CLASSIFICATION OF AQUACULTURE

As mentioned earlier, traditional aquaculture classification system allow the straightforward categorisation of aquaculture according to the production system used and the intensity of culture. However there may be a need for an alternative classification system that will allow planners to *categorise systems according to their ecological risk*. As can be seen from the table on page 213, intensive systems do not necessarily exert the most environmental pressure – for instance intensive closed systems have a very limited environmental impact.

The ecological classification proposed here could be used by planners and regulators as a part of a screening process to determine the level of scrutiny required by aquaculture operations planned or already operating in or adjacent to sensitive areas. Such a classification may be of less use to aquaculture operators, where a code of best practice may be more appropriate (see Section 10.3). For instance, the ecological classification could be embedded into a computerised risk assessment tool that planners might use to identify the main pressures likely to originate from a given system and the likely impact on sensitive environments.

Figure 20: Risk Assessment Tool utilising ecological classification



10 FUTURE MANAGEMENT FRAMEWORK FOR AQUACULTURE IN SENSITIVE AREAS

The environmental impacts of aquaculture have been investigated across the European Union and are generally well understood across a range of systems. Measures employed to mitigate these impacts, including technical advancements, improvements in husbandry and measures at policy and site levels are continuing to develop in parallel to this understanding to meet the growing environmental demands placed by the increasing scale and abundance of aquaculture developments.

However, the employment of, and requirement for, appropriate mitigation measures to reduce impacts upon sensitive habitats across the EU however, can lack cohesiveness. This is exemplified by different standards of practice (e.g. codes of practice, Management Agreements etc) and the regulation and requirements of those standards. In some areas (e.g. Scotland Management Agreement Areas) standards may operate on a voluntary basis while in others, these operate on a stricter, more regulated fashion. The designation status of sensitive areas also means that, for a specific type and size of aquaculture development which could potentially have an impact on a sensitive habitat, the level of mitigation required, either statutorily or otherwise to meet the aims and objectives of the designation is likely to differ. The protection afforded to similar habitats across types of sensitive area is, therefore, also likely to differ.

This section is therefore concerned with a brief analysis of the existing framework for management of the impacts of aquaculture across a range of different sensitive sites. This analysis takes the form of a review of plans and measures adopted in the management of sensitive sites and their application to mitigating the impacts of aquaculture.

The review puts forward both generic and specific proposals that can be adopted and developed into European wide guidelines following further investigation. In assessing the environmental impact of aquaculture in sensitive areas, focus is placed on the major statutory designated areas of conservation and landscape interest. Section 3 has provided a review of the following areas together with a summary of the national/international legislative instruments that support them:

- Biogenetic Reserves
- Biosphere Reserves
- Marine Protected Areas
- Ramsar Sites
- World heritage Sites
- Natura 2000 Sites (Special Protected Areas (SPA) and Special Areas of Conservation (SAC))
- Specially protected areas of Mediterranean Importance (SPAMI)

The differing objectives and status of each of the above suggests that the approach and application of management planning measures will differ across these sites. In some areas, for example, appropriate management may operate on a voluntary basis with mutual agreements between stakeholders forming a management framework. In others, management is required to meet specific criteria set under statutory obligations. This means that the protection afforded to similar habitats across types of sensitive area is likely to differ.

An iterative strategic management approach is proposed that is adaptive and cognisant of individual situations. This is based on the identification of best practice example of existing plans. Within this wider approach to the management of the impacts of aquaculture on sensitive habitats, a number of mitigation measures are discussed at both a regional/ designated site level and at the scale of individual aquaculture developments.

These measures, which effectively take the form of recommended Codes of Practice (COP's), are drawn from a variety of sources including the following:

- Marine Harvest (Scotland) Ltd EIA (2003), Camas Orasaidh, Isle of Lewis, Scotland
- Bass N (2004) Environmental Statement for a proposed Salmon Farm site at Groatay Cheesbay, North Uist, Scotland
- Review and Synthesis of the Environmental Impacts of Aquaculture. Scottish Executive Central Research Unit (2002)
- Hambrey J, Phillips M, Chowdhury KMA & Shivappa RB (1999) Composite Guidelines for the Environmental Assessment of Coastal Aquaculture Development
- M. L. Heffernan (1999) A Review of the Ecological Implications of Mariculture and Intertidal Harvesting in Ireland. Irish Wildlife Manuals, No. 7.
- Federation of Scottish Aquaculture producers (2005) A Code of Good practice for Scottish Finfish Aquaculture.
- Federation of European Aquaculture Producers. Code of Conduct http://www.feap.info/FileLibrary/6/FEAP%20Code%20of%20Conduct.pdf

While a number of these suggested measures are based upon specific types of aquaculture and named developments ('type' specific measures) effort has been made to ensure that recommended approaches are applicable across different types of development in different areas.

In order to clarify this process, aquaculture-induced pressure categories (see Section 5) and the measures appropriate to mitigate these pressures on both a regional and development specific scale are discussed individually. This also has the benefit of further defining these pressure categories and their components. This in turn assists in identifying the impact pathways and where mitigation measures should target and the spatial distribution of habitats/species in relation to the development.

10.1 REVIEW OF MANAGEMENT PLANNING OPTIONS

Building on Section 3, this section discusses the management plans of each of the above sensitive areas and where they are applicable, if at all, to management of aquaculture activities and mitigation of its impacts. As previously noted in Section 3, however, the importance of minimising the impacts of coastal aquaculture to these sites will largely depend upon the habitats and species for which the individual sites are designated.

10.1.1 World Heritage Sites

World Heritage Sites seek to protect sites of natural and cultural heritage. These include museums, ancient monuments, geological heritage and sites of importance for biodiversity. In a number of cases, a World Heritage Site may encompass a variety of heritage values, such as where unique geological formations have precipitated development of a unique flora and fauna. While sharing similar objectives of maintaining the heritage value of an area, management plans for World Heritage Sites will share a breadth of approach commensurate with the range of different sites of heritage value.

Although many elements of aquaculture activities are unlikely to have an impact on cultural heritage, visual and noise impacts are likely to be the most significant in these areas.

Management plans are likely to take the form of high level management objectives and principles with the assessment of impacts undertaken by the Heritage Trust Management Teams through the Member state's existing planning and development controls. In many cases, World Heritage Sites are also designated under national legislation and the existing legislative and management structures are used where possible.

10.1.2 Biogenetic Reserves

Biogenic Reserves have been created to contribute in guaranteeing the biological balance and conservation of representative examples of European heritage; and provide a field of research, for finding out how natural ecosystems function and evolve *(http://ims.wcmc.org.uk/IPIECA2/conven/conven_biogen.html).*

To meet these aims, management must be adequate to ensure the conservation of the sites in the long term in accordance with fixed objectives and under provisions of the Berne Convention (1982) under which the network of sites was originally established. Throughout Europe, sites which are already designated under national legislation are often also designated as Biogenetic Reserves, such as in the UK where they are all SSSI's. Management of aquaculture activities will therefore fall primarily under national legislation as well as under general Bern Convention requirements to maintain or improve the condition of the habitats for which the site is designated. For management purposes, aquaculture developments should therefore ensure that processes are not contributing to the declining condition of designated habitats although there is no reference to specific mitigation measures that are required of such developments.

10.1.3 Biosphere Reserves

Biosphere Reserves are internationally recognised under UNESCO's Man and the Biosphere (MAB) programme launched in 1971. However, they are not covered by international convention, jurisdiction is the responsibility of the nation state. While some countries have therefore enacted legislation specifically to establish biosphere reserves, others have taken advantage of already existing, nationally designated areas, under which to establish biosphere reserves, as with Biogenic Reserves above. A number of reserves may also be supported by other management strategies. Braunton Burrows Biosphere Reserve in the UK for example, is supported by the Taw Torridge Estuary Management Strategy, completed in 1999. This is a non-statutory, high level strategy document which sets out the framework for managing activities within the reserve and wider estuary. The strategy also refers to other plans and legislation which must be adhered to, such as the Biodiversity Action Plans developed in compliance with the Rio Convention (1992). Such plans do not often set out specific thresholds or mitigation measures for activities but refer to aims and objectives for site management.

The example above is a typical example of management and clearly illustrates that management plans, and the approach to managing the impacts of aquaculture developments, will therefore differ across different states as will the level of protection afforded to sensitive habitats.

Management of aquaculture activities is therefore likely to be prioritised depending on the perceived impact of developments on habitats within the site. While specific measures for management of aquaculture activities are likely to be lacking, management guidelines for meeting both quality objectives and criteria for continued designation will, however, have implications for management of aquaculture activities.

10.1.4 Ramsar Sites

Under the Ramsar Convention, designation of sites is justified according to the site meeting a number of listed criteria. These are defined by habitat type and conservation value as well as presence and abundance of wetland species. Management objectives are therefore defined by requirements to maintain those listed habitats and species. To this end, aquaculture developments need to take account of Article 3.1 of the Ramsar Convention which advocates the policy of 'wise use'.

The 'Wise Use Guidelines' (http://www.ramsar.org/about/ about_infopack_7e.htm) call upon Contracting Parties to:

- *adopt national wetland policies*, involving a review of their existing legislation and institutional arrangements to deal with wetland matters (either as separate policy instruments or as part of national environmental action plans, national biodiversity strategies, or other national strategic planning);
- *develop programmes* of wetland inventory, monitoring, research, training, education and public awareness; and
- *take action at wetland sites*, involving the development of integrated management plans covering every aspect of the wetlands and their relationships with their catchments.

Although these are only guideline principles, because of their importance for nature conservation, Ramsar Sites are typically underpinned by other local, national or international designations with legally backed requirements. Colne Estuary Ramsar Site (UK) for example, is also designated as a National Nature Reserve (NNR), Site of Special Scientific Interest (SSSI), candidate Special Area of Conservation (cSAC), Special Protection Area (SPA) and European Marine Site. In many member states, the management of Ramsar sites is implemented through the EU Habitats Directive. More information on the management of sites under the Habitats Directive is provided in the Natura 2000 section below. While overall management objectives are cohesive, aiming to maintain the overall conservation value of the site, strategies to achieve specific targets do differ in specificity of approach. Typically however, the approach to management of all activities is target led, with broad objectives set to maintain water quality and habitat value.

Where activities are perceived to be having an impact upon the site, mitigation measures are broadly discussed but no specific management actions are recommended. Where these are necessary they would form part of more specific investigations recommended within the broader strategy. Management of aquaculture activities is therefore subject to meeting, or not adversely affecting achievement of objectives set under the highest statutory requirements according to site designation.

10.1.5 Marine Protected Areas

Officially promoted in the North-East Atlantic area following the OSPAR Commission meeting in 1998 (see Section 3), the establishment of a network of Marine Protected Areas (MPA's) a number of MPA's were already established both worldwide and within European waters. MPA's are essentially intended to contribute to protection of species and habitats but in many cases also aim to encompass existing resources uses, especially fishing.

In many areas, existing MPA's are established on voluntary agreements between stakeholders such as fishermen and conservation organisations. With the objectives to manage existing marine resources, there is specific reference to management of fishing related activities. Management of these areas therefore include zoning arrangements and multiple use classifications. The MPA may, for example encompass one or two zones where fishing is limited on the basis of effort or gear type, and a 'no take zone' prohibiting all resource use or extraction.

Management of aquaculture activities within this framework is likely, therefore to be on the basis of integrated and voluntary management agreements unless the site forms part of a statutorily designated area. Objectives to maintain the integrity of the site for all uses will likely form the basis of these management agreements. Setting of specific management or operating practices would then be determined separately by the management of any aquaculture facilities, and in consideration of meeting the required objectives. In relation to the above designations, these measures are likely to constitute best practice but still lack statutory backing which would assist in enforcing such practice to meet overall site or zonal objectives.

10.1.6 Natura 2000 Sites

As previously noted, Natura 2000 sites represent a European network of protected sites of the highest value for natural habitats and species which are rare, endangered or vulnerable within the European community. The network is made up of SPA's and SAC's designated for their importance to bird species and habitats. These are strictly protected under the EC Birds Directive (79/409/EEC) and EC Habitats Directive (92/43/EEC) respectively, with each transposed into national law. The Habitats Directive requires management of the sites to be undertaken through a site management plan (as set out in the Directive). The Directive calls for a single management plan for each site and should list activities which are likely to have an adverse effect on the site designation, with accompanying threshold levels/objectives for each feature of interest.

Under these directives, and in adoption of the precautionary principle, projects are only permitted if they can prove no adverse impact on the integrity of site designation, unless accompanied with a justification for overriding public interest and suitable compensatory measures secured. Management Schemes and Plans for both SACs and SPAs follow statutory requirements for Member states to establish conservation measures which correspond to the ecological requirements of the designated habitats and species. Furthermore measures should be taken to avoid deterioration of natural habitats and habitats of species as well as significant disturbance of species, for which the site is designated. For SAC's these are the Annex I habitats and Annex II species present on the site, while for SPA's these are SPA designated birds species, including assemblages, and also their habitats (designated as sub-features and the basis of conservation objectives).

Management plans for SPA and SAC sites are developed on the basis of advice given by Member States nature conservation advisors. The management plans are based upon the conservation objectives of the site and should be written as to provide information on:

- understanding the international importance of the site, underlying physical processes and the ecological requirements of the habitats and species involved
- advice to relevant authorities as to the conservation objectives for the site and operations which may cause deterioration and disturbance;
- setting the standards against which the condition of the site's interest features can be determined and undertake compliance monitoring to establish whether they are in favourable condition;

These standards provide the most detailed information in terms of assessing and monitoring impacts of human activities (including aquaculture) on the designated site and upon which impacts and mitigation measures can be monitored. The plans should identify the target conditions of each interest feature (habitat/species) and therefore act as trigger mechanisms for any mitigation measures to be put in place through aquaculture (and other) developments. The plans should also set out monitoring programmes. However, in many cases they do not specify individual mitigation measures for specific activities but are related to the impacts on the receptors as discussed in Section 6.

It is clear that activities undertaken in such sites are, therefore, subject to a greater interrogation of impacts than those in any other areas. With regards to aquaculture developments within sites, and due to the potentially wide range of adverse impacts associated with their operation, aquaculture developments will be required to meet the highest standards of practice in order to prove no adverse impact. These standards will necessarily include suitable monitoring regimes and development of appropriate mitigation measures to reduce any potential impacts.

Where management plans follow recommendations to meet the standards of the Habitats Directive, a key measure used to maintain site integrity is that developments, plans and measures must be able to show no adverse impact on habitats and species for which the site is designated. Sensitive areas should therefore be based upon named habitats and species, or assemblages of species. From this point, management objectives may become more specific in their requirements. Mitigation measures for example, include measures adapted from Regulation 33 Guidance for management of European Marines Sites in the UK. These measures include requirements to maintain the extent and distribution of habitats and the presence and abundance of species.

10.1.7 Specially Protected Areas of Mediterranean Importance (SPAMI)

Impacts from aquaculture must be minimised to prevent any deterioration to such sites. Management of aquaculture activities falls under a number of high level objectives defined under the Convention for the Protection of the Mediterranean Sea against Pollution (the Barcelona Convention 1976).

Forming the basis of management plans, these objectives are widely applicable to any aquaculture activities with contracting parties required to 'comply with the measures applicable to the SPAMIs and not to authorise nor undertake any activities that might be contrary to the objectives for which the SPAMIs were established' (http://www.oceanlaw.net/texts/unepmap2.htm). In order to do this parties are required to 'identify and compile lists of the endangered or threatened species of flora and fauna and accord protected status to such species'. The parties shall also 'regulate and, where appropriate, prohibit activities having adverse effects on such species or their habitats, and carry out management, planning and other measures to ensure a favourable state of conservation of such species'. As with other protected sites, while specific national legislation may in some cases be drawn up to manage SPAMIs, notification of a SPAMI is likely to be underpinned by established national or internationally designated sites. Lists of habitats and species to be protected are likely to be drawn from Annex I and II of the Habitats Directive respectively. Where a SPAMI is also designated as a SPA, species lists are similarly likely to be drawn from Annex I and II of the Birds Directive. Management plans for such sites will therefore be subject to meeting those objectives of the SAC and or SPA sites and therefore the higher statutory requirements of the Habitats and Birds Directives. Where a SPAMI is underpinned by national or European designations, management plans will in turn be led by relevant national or European legislation.

As well as national or international legislation applicable to SPAMI management plans, the Barcelona Convention also requires a number of specific provisions which would be directly applicable to management of aquaculture activities:

- the strengthening of the regulation of the release or dumping of wastes and other substances likely directly or indirectly to impair the integrity of the area;
- the strengthening of the regulation of the introduction or reintroduction of any species into the area;.

Where such legislation does not exist, however, the requirements of the Barcelona Convention should ensure that management plans are suitably robust to afford a high level of environmental protection.

10.2 SAC MANAGEMENT PLANNING MEASURES

Background: the above review of management frameworks for the different designations covering environmentally sensitive areas clearly highlights that the protection afforded to sensitive habitats from plans and developments varies according to the designation status of the site. In many cases, single areas have multiple designations. Even where sites may have a common designation, for example as a Marine Protected Area, difference in the status of the different underpinning designations for those sites and habitats may mean that the level of protection across similar habitats still remains inconsistent. For aquaculture, this means that codes of practice, including requirements for mitigation and monitoring of impacts, are not necessarily required to meet the same standards.

To avoid this conflict of interest, management plans and measures should therefore meet the requirements of habitat protection set under the widest applied and most robust designations. The adoption of this approach is also in line with actions envisaged in the EC Biodiversity Strategy and in the Biodiversity Action Plan for Fisheries (http://biodiversity-chm.eea.europa.eu/), and is expected to contribute to the objective of halting biodiversity loss set by the 6th Environmental Action Programme and by the EC Strategy for Sustainable Development. It will also contribute to fulfilment of the aims of Agenda 21, agreed at the Rio Earth Summit in 1992 (http://www.un.org/ esa/sustdev/documents /agenda21 /english/Agenda21.pdf).

Following review of management frameworks, it is therefore recommended that any subsequent aquaculture guidelines seek to fit the requirements of the Habitats and Birds Directives as applicable to Natura 2000 site management. Applied across the EU, the Directives should already be transposed into national legislation and thereby provide a suitable framework within which guidelines and measures to reduce the impacts of aquaculture on sensitive habitats can be developed. Furthermore, it should ensure that a single management plan covers all activities within a site and therefore be able to consider the cumulative effects of different types of development within a site and the impacts upon the environmentally sensitive features for cross comparison across Europe. The approach would be constructed around a robust and consistent pan-European methodology for monitoring and mitigating for aquaculture impacts and understanding impacts in respect of other activities. Employing the Directive approach to management and mitigation, as applicable to Natura 2000 sites, should ensure that:

- Sites should be managed in order to contribute to the maintenance or restoration of the favourable conservation status of their natural habitats and species.
- Appropriate steps are taken to avoid the deterioration of the habitats, the habitats of the species or the disturbance of species for which the site has been designated.
- Activities, plans or project may only proceed when it has been ascertained that they will not adversely affect the integrity of the site concerned.

Development of management plans and mitigation measures using this approach should establish best practice approach and should be taken forward. Furthermore, by establishing a set of robust requirements for management of sensitive habitats across all sensitive areas, this framework would also help to meet the requirements of the Water Framework Directive which are applicable to coastal, estuarine and freshwater systems including those that are already modified. Mitigation measures may therefore also be viewed in the context of the requirement for all sites to meet 'Good Status' or show no deterioration in status. Good status in this case means meeting a particular ecological and chemical condition which is set against quality benchmarks.

Embedding aquaculture interests into this process – role of the 'Appropriate Assessment': Natura sites (Special Areas for Conservation (SACs) and Special Protection Areas (SPAs)) designated for habitats and species which could be sensitive to aquaculture include:

- cSACs with a marine element;
- cSACs that support salmon and/or freshwater pearl mussels (dependent upon salmonids for the early stage of their life cycle) as qualifying features;
- terrestrial cSACs immediately adjacent to the marine environment and where otter is a qualifying interest; and
- SPAs which contain species that will have a direct interaction with the operational areas in the marine environment, and those supporting species in intertidal areas that could be disturbed by offshore activity or by shore based support activities, or affected by pollution.

SPAs and SACs form a network of protected areas designated under the Habitats Directive and Birds Directives. The Conservation (Natural Habitats &c.) Regulations 1994 require that where an authority concludes that a development proposal is likely to have a significant effect on a European site (even if the development is outwith the site), it must undertake an appropriate assessment of the implications for the conservation interests for which the area has been designated. For example, salmon cultivation beyond the mouth of cSACs with salmon and pearl mussel qualifying interests is likely to require an appropriate assessment of the likelihood of a significant effect upon them. The determination of the actual sensitivity of a prioritised marine (benthic) habitat to parameters such as organic enrichment and reduced dissolved oxygen will form part of any appropriate assessment required under the regulations mentioned above.

The Appropriate Assessment forms the backbone of the protection regime for Natura 2000 sites, along with conservation management plans. However in many Member States, for example, it is clear, that directives are not being adhered to for important marine nature sites. Despite clear legal requirements very few impact assessments are undertaken of proposals, either individually or cumulatively. Potentially, significant aquacultural developments should all be subject to appropriate assessment.

An example of the use of appropriate assessment is provided in the box overleaf. This demonstrates the function that such an assessment can perform in identifying the specific problems associated with aquaculture development and sensitive areas and the potential contribution to environmental management at farm level. It is interesting to note the emphasis on integrating the mitigation proposals into overall Area Management Arrangements (AMA) through the coordination of production cycles as well as major husbandry interventions e.g. lice treatment. The Appropriate Assessment also makes reference to the need for skilled and trained staff and the adherence to the newly published "Code of Good Practice For Scottish Finfish Aquaculture".

Box 6: Appropriate Assessment of the implication of salmon farming on the conservation interest of the Little Gruinard SAC

Background	In 2002 a company applied for permission for a cage farm to rear 1,500 t salmon on the first year then 1,300 t cod annually thereafter. The Little Gruinard River is 15 km away and is designated an SAC due to its Atlantic salmon population.
Assessment of potential impacts	1. High numbers of sea lice impacting on wild SAC Atlantic salmon. 2. Interference with wild SAC Atlantic salmon migratory routes. 3. Escapee risk to the wild Atlantic salmon in the SAC. 4. Disease transfer to wild SAC fish. 5. Failure to synchronise production with adjacent operators. 6. Cumulative fish farm impacts.
Potential mitigation measures	• Develop and implement an effective escapes prevention plan to minimise the occurrence of escapees, agreed as part of the Area Management Arrangement (AMA); • Develop and implement an effective anti-predator plan to minimise the occurrence of escapees, agreed as part of the AMA. Such a plan should focus on the prevention of damage to nets by seals, for example through net design/protection and seal scrammers and not primarily through shooting, which can only take place when staff are present; • Develop and implement an effective fish hygiene/disease prevention and treatment plan (diseases may occur and will need to be treated immediately), agreed as part of the AMA; • Develop and implement an effective sea lice management/control plan, agreed as part of the AMA; including the most effective available treatments, stocking and fallowing for sea lice, in accordance with the SEPA discharge consents; • Develop and implement synchronised production with adjacent operators through the development of an AMA; • An AMA should be in place before production at Annat Bay commences; • Use professional and experienced staff; and • Agree to develop and implement appropriate monitoring, recommended through the AMA, and to make this information publicly available to help inform the development of the AMA.
Summary	Based on the nature of the proposed fish farm operation, it is considered that the Annat Bay site has the potential to have a significant impact on the qualifying features of the Little Gruinard River SAC for the one salmon cycle proposed. However, if a series of effective mitigation policies and procedures relating primarily to disease/hygiene, escapees, predation, sea lice control and synchronised/coordinated production through an agreed AMA are developed and adhered to, it is considered that the proposal would not significantly impact on the qualifying features of the Little Gruinard River SAC.

Source: EnviroCentre, 2005

10.2.1 Aquacultural Activity Strategic Guidance

Based on the results of Section 7 (Risk Identification and Ecosystem Vulnerability), the following provides guidelines on those aquaculture activities that should be excluded from operating in sensitive sites. This guidance is based on the risk of impacts to sensitive habitats and species, and is intended to operate as a 'front line' mitigation measure to reduce the environmental impact of aquaculture developments.

The potential impacts of different aquaculture activities and risk to habitats have previously been discussed. Guidance is therefore limited to recommendations concerning non-permissible aquaculture activities with a summary of risk to habitats by means of explanation.

Cage farms: risk matrices indicate a high level of risk across all marine habitats as a consequence of two main pressure categories; sedimentation and change in biochemistry. A high level of risk is also associated with four other pressure categories and site integrity is therefore likely to be adversely affected by cage farming practices. The matrices also indicate that a number of species groups are at high risk of adverse impact. Moderate to negligible levels of risk are associated with coastal habitats although cage farms are limited to marine sites. For a number of pressure categories, while impacts may be mitigated to some extent, the open nature of this aquaculture practice means that a number of impacts, such as sedimentation, are unavoidable. Siting of these systems in proximity to sensitive habitats means that risk and impact to such habitats is inevitable, regardless of practices once the site has been established.

Permissible within sensitive areas: Subject to further appraisal.

Shellfish rafts and longlines: the pattern of high risk to marine habitats is similar as that for cage farms, with the main exception being the risk of impact associated with chemical use is graded as negligible. Due to the economics of this aquaculture practice, rafts and longlines are typically arrayed in extensive arrays, therefore impacting upon a relatively wide area.

Permissible within sensitive areas: Subject to further appraisal relating, for example, to scale of development and importance of area to listed species or critical habitats.

Inter-tidal shellfish culture: the generally extensive nature of shellfish farms results in a moderate to negligible level of risk across the majority of habitats and species groups. However, their presence within important bird feeding and fish nursery areas means that they may have an impact on the integrity of sensitive sites. There are concerns over the high risk of impact due to introduction of alien species, although management of this risk based on a permit system is likely to prove relatively easy to enforce.

Permissible within sensitive areas: Subject to further appraisal relating, for example, to scale of development and importance of area to listed species or critical habitats.

Bottom shellfish culture: typically considered as a low impact approach, only the introduction of alien species poses a high risk to a number of sensitive habitats. Risk of impacts due to other pressure categories, such as sedimentation, is generally associated with harvesting operations rather than growth periods. Categorisation of moderate risk to a number of sensitive habitats due to sedimentation and infrastructure impacts is likely to represent a precautionary viewpoint as bottom shellfish culture typically takes place over 'clear' substrate such as sands and muds. Impacts to other habitats will depend on their proximity to the farmed area.

Permissible within sensitive areas: should not be permissible in very sensitive sites.

Land–based tank systems: the main pressures associated with these systems are related to infrastructure and use of chemicals. High risk to saltmarshes, sand dunes and shingle habitats due to infrastructure should be able to be manageable through suitable planning policy. Furthermore these habitat types do not provide ideal site conditions for these systems. Similarly, outputs of chemicals or pathogen transmission that may be deleterious to habitats and fish species, can also be adequately managed through maintenance of good management procedures and appropriate treatment facilities.

Permissible within sensitive areas: Subject to further appraisal relating, for example, to scale of development and importance of area to listed species or critical habitats

Land-based pond systems: risk to habitats and species from land based pond systems is commensurate with cage culture, with a high level of risk to both marine and coastal habitats associated with a number of pressure categories. The requirement of these systems for large areas of land is noted as one of the greatest risk to habitats, with potential adverse effects on the ecological integrity of the wider area, especially in the case of saltmarshes. Impacts to marine habitats as a consequence of effluent release from pond systems has been a major problem in tropical zones. Although potential for such impacts exists in Europe, regulation is tighter but needs strict monitoring.

Permissible within sensitive areas: Due to large land requirements, operations are likely to effect the integrity of sensitive sites, especially those where saltmarshes are affected with resultant impacts upon essential bird and fish habitat.

Lagoon culture: although lagoon culture has typically operated extensively, developing methodology has resulted in the intensification of production and therefore increased the risk of impacts to associated habitats. Although not listed as a sensitive habitat, coastal lagoons, within which farming is typically based, frequently exhibit a unique biodiversity which is threatened by farming practices such as the artificial retention of water in the system and stocking of non-native species. Risk of impacts to other marine and terrestrial habitats and species is generally moderate to negligible, although changing the water level patterns across sand and mudflats may constitute a significant disturbance risk. Risk of impacts due to the introduction of alien species is high although the effects of such introductions are still being assessed. The impacts of these may be widespread and therefore use of alien species within lagoon systems needs firm regulation.

Permissible within sensitive areas: Although the risk of impacts from lagoon culture to habitats and species are typically moderate to negligible, natural lagoons, within which aquaculture typically develops, frequently represent unique habitats with a specialised biodiversity. Changes to the lagoon system may impact spawning and nursery areas for fish species and feeding areas for bird species. While risk may be moderate to negligible, impacts to site integrity may therefore be significant.

10.3 CODES OF PRACTICE FOR AQUACULTURE IN SENSITIVE ENVIRONMENTS

Codes of Practice (CoP) for marine aquaculture are in operation in parts of Northern Europe. In general, these CoPs have been designed for the regulation of the marine aquaculture of salmon (*Salmo salar*) and rainbow trout (*Oncorhynchus mykiss*). In general, the industry has become increasingly aware of the positive effects of CoPs, and some countries have developed their own (for a list of the benefits of CoPs see Box 5 on page 169). There is much variation amongst North European countries regarding the content of CoPs and the implementation of such Codes into national legislation.

Because scales of aquaculture and methods of operation vary, even within distinct aquaculture practices, establishing a set of guidance principles relating to permissible types and scale of development is open to error. Permission for development should therefore be subject to meeting criteria of proof of 'no adverse impact' to designated features within a site. Where aquaculture developments are authorised to proceed, they would then be subject to meeting management requirements such as those relating to habitat extent and species presence described above. In this manner aquaculture developments that may have otherwise have been prohibited within sensitive areas may proceed on the basis of employing stringent CoP. This will also provide an incentive for aquaculture producers to adopt high standard COP's, as larger operations would be allowed on the basis of proving they will not impact site conservation management objectives. This should also close any loopholes in permissions based on scale, where small, permitted developments, allowed on the basis of expected minimal impact, might otherwise have a disproportionately large impact on sensitive sites. Permitting aquaculture in sensitive areas may therefore be assessed according to these measures.

10.3.1 What is a Code of Practice?

According to the Federation of European Aquaculture Producers (FEAP) a Code of Practice should:

- be voluntary or non-voluntary ;
- advocate and promote 'best practices';
- interpret standards issued by the competent authorities and/or provide "industry standards" where laws and regulations do not fulfil the industry's needs; and
- develop a process of consultation, negotiation and agreement between stakeholders and inflicted parties.

10.3.2 Existing Codes of Practice for Aquaculture around Europe

In Northern Europe there are different types of Codes of Practice, relating to the development of aquaculture and its regulation in the different countries. Examples range from general to specific and include the FAO Code of Conduct for Responsible Fisheries (CCRF), and the associated Technical Guidelines which relate specifically to aquaculture.

FEAP's Code of Conduct[22] is a 9 page document that provides guiding principles that are generic across the different species and scales of European aquaculture. It makes reference to a number of existing guidance documents that, in addition to the FAO CCRF includes:

- The Holmenkollen Guidelines for Sustainable Industrial Fish Farming (Oslo - 1994).
- The Holmenkollen Guidelines for Sustainable Aquaculture (Oslo - 1997).

[22] http://www.feap.info/FileLibrary/6/FEAP%20Code%20of%20Conduct.pdf

- The ICES Code of Practice on the Introductions and Transfers of Marine Organisms (Copenhagen 1994).
- Codes of Practice and Manual of Procedures for Consideration of Introductions and Transfers of Marine and Freshwater Organisms (EIFAC -1988).
- The Report on the Welfare of Farmed Fish (Farm Animal Welfare Council (U.K.) - 1996).

In *Ireland* there are various voluntary environmental Codes:

- The BIM (in association with the Irish Shellfish Association (ISA) and the Irish Salmon Growers Association (ISGA)) *Environmental Code of Practice for Irish Aquaculture Companies and Traders* (EcoPact) and the ISGA Code – "*Good farmers – good neighbours*"
- National and local *Co-ordinated Local Aquaculture Management Strategy* (CLAMS) Codes. These Codes are similar to the local management strategy plans used in Norway. CLAMS plans are joint development strategies for bays with agreed procedures for many issues, such as waste disposal, importation of seed and colour of equipment, which have been agreed by the management committee for each bay.

A governmental co-ordination of regulations has begun, with protocols on benthic monitoring, water quality monitoring, fallowing of sites, sea lice monitoring and audits of fish farms.

In *Scotland*, Shetland has adopted *Shetland Salmon Farmers Association Code of Best Practice*. This Code incorporates many of the regulations, such as stocking policy, density, smolt delivery, health management, stock husbandry and different environmental issues, which are applicable in mainland Scotland. Members of Scottish Quality Salmon and Shetland Quality Salmon have to abide by EN 45011 standards. The introduction of the Code of Good Practice at a national level for all finfish species is very relevant to the industry in Shetland. The comprehensive (40 pages plus annexes) *Code of Good Practice for Scottish Finfish Aquaculture* (2006) has evolved from the Strategic Framework for Scottish Aquaculture and provides a "valuable alternative to detailed regulation of every aspect of an industry's activity". A permanent industry steering group of 4-6 people is tasked with ensuring that the CoP remains up to date with the industries development. This CoP also encompassed the lessons from various guidance papers associate with the industry, including:

- A Code of Practice to Avoid and Minimise the Impact of Infectious Salmon Anaemia
- The SQS[23] Predator Code of Practice
- The SQS Environmental Management Guidance Manual
- SQS/SSFA Code of Practice on Containment
- Gyrodactylus Code of Practice

Trout farming in England is also covered by the UK-wide *British Trout Association Code of Practice.*

In France, the Inter-professional Committee has produced a Charter for Trout Producers. In Italy, there are three detailed Code of Practice for responsible trout, sea bass and sea bream production.

In Spain, the Ministry of Environment and other have published the *Manual de Buenas Practicas Medioambientales en la Familia Profesional: Pesca y Acuicultura.* This is divided in different sections including (i) equipment and inputs, (ii) bad practices not to carry out, (iii) good practices, (iv) resource management (energy conservation, product consumption and waste and pollution management and (v) a self-assessment process.

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[23] Scottish Quality Salmon

10.3.3 Framework for a Code of Practice for Aquaculture in Sensitive Environments

The existing Codes of Practice operate at various levels. For instance, the FEAP CoP is generic across Europe and provides guiding principles for all forms of aquaculture, regardless of species and scale. In contrast, the Scottish finfish CoP provides precise recommendations for best Practice for finfish aquaculture in the particular conditions of the Scottish highlands and islands.

Given the existence of a number of species and country-specific CoPs, it is considered that any new CoP (hereafter referred to as a EU Code of Practice for Aquaculture in Sensitive Coastal Areas, COPASCA) emerging from this initiative should:

- Reflect and operate within the FEAP Code of Conduct as well as other generic CoC e.g. the FAO Code of Conduct for Responsible Fisheries;
- Be specific for marine and coastal aquaculture that may impinge – directly or indirectly – on environmentally sensitive areas as defined by this report;
- The guidance contained in the CoP should be primarily aimed at investors and operators in the European aquaculture industry. The document should also provide useful information to planners, regional managers and regulators involved in aquaculture development in sensitive areas.

It is suggested that the COPASCA be divided into three different sections:

- **Background and Guiding Principles**: provides the scope and objectives of the CoP, followed by a vision and guiding principles for coastal aquaculture in sensitive environments. Would provide definitions and linkages with existing codes of practice and codes of conduct form Europe and elsewhere.
- **Planning and Siting of Aquaculture in Sensitive Areas**: provides guidance on the planning and siting of aquaculture in sensitive areas. This should be provided at two levels:
  - Regional level: integration into regional planning and coastal zone management initiatives. Needs to recognise the cumulative impact of aquaculture in and around sensitive sites and thus provide guidance on suitable instruments such as Strategic Environmental Assessment and the Water Framework Directive.
  - Site-specific level: guidance on the planning and siting of quantifiable aquaculture developments. Could utilise the system-specific pressure and risk analyses in this report to (i) identify tools and mechanisms to further quantify and model the pressure outputs, ecosystem sensitivity and resultant risk and (ii) to then suggest where design-related mitigation options may lie. This guidance might be integrated into the overall environmental impact assessment (EIA) process.
- **Operation and Maintenance of Aquaculture in Sensitive Areas**: aimed at aquaculture operators, this section would provide guidance on established good Practice and mitigatory approaches to both (i) minimise the pressures originating from the farm as well as (ii) maximising the potential for assimilation and risk reduction through environmental planning and management.
- **Implementation mechanisms**: practical guidance and assistance for integrating the above good practice recommendations into recurrent planning, management and operational procedures.

This outline framework is detailed further in the table overleaf.

Table 49: Outline Framework for a Code of Practice for Aquaculture Development in Sensitive Areas

Section	Sub-section
A. Background and Guiding Principles	**Background** • Introduction • European coastal aquaculture and potential impacts on sensitive areas • Objectives of the CoP • Intended Target Audience • Definitions (details in annex) **Guiding Principles** • Vision for the responsible development of aquaculture in sensitive areas • Guiding Principles
B. Planning and Siting	**Regional Planning** • Integration into SEA, ICZM • Use of environmental capacity assessment for specific regions and waterbodies **Site Selection** • Use of site-specific environmental capacity assessment • Determination of impact scale and magnitude • Assessment of habitat sensitivity and risk • Guidance on cumulative impact assessment with other planned and existing operations • Guidance on farm design mitigation options to reduce the magnitude, duration and distribution of its environmental pressures.
C. Operation & Maintenance	**Pressure reduction approaches** • Reducing sedimentation • Reducing change in bio-geochemistry • Reducing infrastructure impacts: • Reducing land & seascape modification: • Reducing disturbance: • Guidance on predator control: • Responsible chemical use: • Reducing pathogen transmission: • Conserving natural biodiversity: **Environmental management approaches** • Guidance on site rotation and fallowing • Guidance on separation and buffer zoning • Regional coordination and joint waterbody management
D. Implementation mechanisms	• SEA and EIA tools • Environmental impact assessment • Environmental capacity assessment • Environmental management systems • Appropriate assessment (as part of Natura 2000 management)

10.4 RECOMMENDATIONS FOR FUTURE ACTION

10.4.1 Marine Aquaculture and Integrated Coastal Zone Management

Coastal aquaculture has great potential for the production of food, alleviation of poverty and generation of wealth for people living in European coastal areas. Despite this, aquaculture often falls short of its development potential, and is sometimes associated with social and environmental problems.

In many ways aquaculture is a classic example of why more integrated coastal management is needed. Aquaculture may be seriously affected by water quality and habitat degradation caused by other activities. It may itself affect environmental quality and the interests of other users through conversion of natural habitat; through pollution of recipient waters with nutrients, organic substances, and potentially toxic (hazardous) chemicals; and through the spread of disease. Poorly sited or planned aquaculture may result in negative feed-back and self pollution. Resource ownership or rights allocation, and related administration, is often complex or ambiguous in prime aquaculture locations.

It is recommended that a specific evaluation of the link between ICZM and aquacultural development in Europe is addressed. The outcome of such an exercise would:

Produce guidelines for planning of sustainable coastal aquaculture: this would provide policy makers and higher level decision makers with a set of guidelines and general principles to meet the challenge of sustainable aquaculture development through broader policy initiatives.

Produce planning and management tools for coastal aquaculture development: this would provide more detailed technical information on the various tools available to implement these guidelines in practice. This would targeted at project managers, government agencies, commercial and producer organisations, and others directly involved in coastal aquaculture development.

Detailed case studies in coastal aquaculture development planning: taking forward the work carried out in this report, present a range of examples of the planning and management of aquaculture development in practice, from around Europe ranging from limited sectoral approaches to comprehensive integrated coastal management. These case studies would provide a detailed insight into the success or otherwise of different approaches to aquaculture development planning in a wide range of physical, ecological and development contexts, and serve as the underpinning for the general principles presented above. They will be of interest to professionals involved in coastal management, and will be of particular value to trainers and teachers of coastal management.

Integration and co-ordination guidance with other sector activities or plans: needs to undertaken with national sector plans and with wider coastal management initiatives where these exist. Identification of appropriate institutions, including resource user representative organisations to promote integration and co-ordination; to ensure effective implementation of planning measures; and to allow for effective monitoring and feedback.

Demonstrate participation and consultation of all stakeholders: participation and stakeholder consultation should be a key principle in policy development and objective setting.

Economic evaluation of costs and benefits (financial, economic, social, environmental) of aquaculture development, and alternative resource uses in a specific area: this would assess financial and economic incentives, whether these derive from markets, fiscal measures, or the provision of infrastructure, should be used in preference to regulation wherever possible;

Outline of tools and techniques: for institution building and issues identification.

Assessing assimilative capacity: build upon recent developments regarding estimates of assimilative capacity where aquaculture is in balance with other users.

Modelling: develop models to simulate scenarios and aid with management. Progress with use of models in a wider context in the management of aquaculture.

Locational guidelines: as part of the ICZM process, develop detailed location guidelines for each Member State, taking into account particular habitat sensitivity and socio-economic conditions.

Environmental assessment: provide guidance on the increased level of environmental assessment required in 'sensitive areas'.

Research: target research to focus on sensitivities and the requirements of the conservation of habitats and species in cohesion with the Habitats and Birds Directives and other relevant legislation.

10.4.2 Code of Practice for Aquaculture in Sensitive Coastal Areas

This report suggest the outline of a '*Code of Practice for Aquaculture in Sensitive Coastal Areas'* (COPASCA). It is recommended that this is further developed to produce a guidance document for both Member State planning and regulatory authorities as well as aquaculture developments and operators – as discussed on page 230 this framework in structured at two levels to benefit these different interests. This CoP should be built upon the platform of existing guidance (e.g. the FEAP Guiding Principles as well as the various industry CoPs) and ensure that it:

(i) was coherent with current and proposed EC policy and actions in both nature conservation as well as aquaculture development;

(ii) was specific for aquaculture in sensitive areas rather than a re-issue of previous environmental management guidance; and

(iii) provides practical tools and advice for both planners and operators.

10.4.3 Development of a Decision-support Tool

This report suggests the possible use for an ecological classification of aquaculture in the development of a 'decision-support' tool for planners and developers when setting up aquaculture in or adjacent to sensitive areas. The process illustrated in Figure 20 provides a risk assessment tool that would use the classification and pressure/habitat sensitivity linkages to identify impacts. This tool could be made extremely powerful if it could be linked to the Natura 2000 database so that (i) the location of sensitive areas can be identified quickly and (ii) that the features of conservation interest could also be flagged up. This would then allow users to identify possible risks to these conservation areas based on (i) the class of aquaculture system involved and (ii) the scale of production. If this were combined with a spatial database of aquaculture activities (see next recommendation), then cumulative impacts could also be assessed on a wider (zone C) scale.

10.4.4 GIS Recommendations

While it is possible to gain an appreciation of the spatial relationships between areas of aquaculture and environmental designations, this study shows that due to a lack of data at member State level, it is not possible to do so in any great detail with the existing datasets. In order to perform a detailed spatial intersection between environmental and aquaculture data it is necessary to understand the precise location of aquaculture sites around Europe. Ideally, a central coordinate or bounding polygon representing the extents of each particular aquaculture site should be acquired. Until this information is available it will only be possible to investigate aquaculture sites to the level of NUTS 2.

Appendix A: Terms of Reference

Reference No FISH/2004/15:
Some Aspects of the Environmental Impact of Aquaculture in Sensitive Areas

TECHNICAL SPECIFICATIONS

Brief description of the study

The study will identify best practice for conducting aquaculture in environmentally sensitive areas, particularly those designated under Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora, so as to reduce negative impacts. It will provide information which can be used to develop a code of practice for marine aquaculture operators by examining the location and scale of aquaculture activity in protected sites and examine the desirability of a zoning system to better protect the nature interests of sites. Proven and likely impacts on the habitat will be examined, including habitat occupation and nutrient loading. The relationship between nutrient loading and algal blooms will also be studied. A methodology will be suggested for the design of appropriate management plans in the context of Article 6 (1) of Directive 92/43.

Background to the study

EU aquaculture production grew from 642,000 tonnes in 1980 to 944,000 tonnes in 1990 and reached 1,315,000 tonnes in 2000 with the assistance of EU structural assistance. Its value is currently in the area of €2,500 million per year and its principal products are salmon, trout, sea bass, sea bream, oysters, mussels and clams. Aquaculture constitutes 17% of the volume and 27% of the value of total fishery production of the EU. In some regions, however, aquaculture has a poor public image and is facing criticism for its negative environmental effects.

There is an overlap between marine aquaculture production areas and the protected nature sites of the Natura 2000 network. The Community is committed to this network of protected sites for certain wild birds, animals and plants, and a range of habitat types. The "bird" component of Natura 2000 derives from Directive 79/409/EEC and the "non-bird" component from Directive 92/43/EC. The network is particularly relevant to shellfish farming but there is also overlap with fish farming sites. Aquaculture frequently takes place in wetlands of international importance for birds (frequently found in estuaries and sea inlets). It can also take place in lagoons, large shallow inlets, bays and salt meadows. It is therefore crucial that the future development of aquaculture incorporates a decoupling of industrial growth from environmental damage.

Environmental protection requirements are being integrated into the Common Fisheries Policy; the Communication from the Commission COM(2002)186 sets out a Community action plan relating to this process. Other relevant background documents are the Biodiversity Action Plan for Fisheries, COM(2001)162 final, Vol. IV and the Recommendation of the European Parliament and of the Council concerning the implementation of Integrated Coastal Zone Management (Recommendation 2002/413/EC) which calls on Member States to take stock of factors affecting the coastal zone, including aquaculture and calls for the Member States to develop strategies to implement the principles of integrated management of the coastal zone.

Purpose/objectives

The objective of this study is to analyse the interactions between different aquaculture facilities and the species and habitats in their vicinity, to determine the compatibility of fish and shellfish farming with nature conservation policies and, ultimately, to outline best practices for conducting aquaculture in environmentally-sensitive areas, providing information which can be used to develop a code of practice for marine aquaculture operators.

Terms of Reference

- To examine the location of aquaculture activities in relation to sensitive conservation features such as bird feeding areas, or fish or shellfish nursery areas, and to propose a systematic classification of fish and shellfish farms in relation to their likely or proven impact on the environment.
- To review the scale of developments (including stocking levels in relation to the carrying capacity of sites) and their cumulative effect on the environment. On this basis, to define thresholds for these developments for significant effects on native species and other ecological impacts. Special attention should be paid to the following effects:
    - long term impacts on habitats (e.g. sedimentation from shellfish pseudofaeces and fish faeces) and on productivity of the ecosystem;
    - algal blooms in the surrounding coastal zone triggered by nutrient loading from cage culture.
- To propose measures that should be included in the management plans foreseen in Article 6(1) of Directive 92/43/EC in order to cope with the possible interactions aquaculture/environment.
- To suggest aquaculture practices for new plans or projects of fish and shellfish farms in sensitive areas that are compatible with the maintenance of sensitive areas in a good status of conservation.

Geographical Coverage

Relevant coasts of the Community and case studies from the Community and other areas of the world with similar geographical conditions.

Information available

COM(2001)143, COM(2001)162 final Vol IV, COM(2002) 186 final, reports of the Fisheries DG (including report of a seminar on shellfish farming and integrated development held at La Rochelle, November 1995) reports of Environment DG, (including Natura 2000 network information and relevant Life Nature projects) reports of international organisations and governmental reports.

Methodology

Kick-off meeting in Brussels; preliminary desk work; production of discussion documents, organisation of a seminar, production of draft final report, meeting in Brussels to discuss the draft report before final acceptance.

Timetable and reports

The kick-off meeting shall take place in Brussels within two weeks from the signature of the contract. A progress report shall be sent to the Commission between the fifth and the sixth month. The first draft of the final study report should be made available within ten months of the signature of the contract. The draft final report to be submitted within 12 months.

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Appendix C: Finfish Production in the EU by Country

Belgium (BE)

Species	Product	1997	1998	1999	2000	2001	2002	2004	2004*
Carps	Common Carp	300	300	400	400	400	400	400	400
Catfish	African Catfish	150	150	200	250	250	250	250	250
Eels	European Eel	150	150	40	20	20			
Sturgeon	Sturgeons nei	2	2						
Tilapias	Tilapias nei	300	300	200	150	150	150	150	150
Trout	Pink Rainbow trout	100	100	100	200	200	250	250	250
	White Rainbow trout	600	600	600	400	400	250	250	250
	Large Rainbow Trout	120	100	100	100	100			
Grand Total		**1,722**	**1,702**	**1,640**	**1,520**	**1,520**	**1,300**	**1,300**	**1,300**

Cyprus (CY)

GROUP	Product	1997	1998	1999	2000	2001	2002	2003	2004*
Sea Bass	European Seabass	58	204	298	300	300	421	500	500
Sea Bream	Gilthead Seabream	768	830	986	1,200	1,300	1,260	1,500	1,500
	Silver Seabream	25							
	Striped seabream		25	28	100	100			
Trout	Pink Portion Rainbow Trout	105	90	66	90	90	180	90	90
Grand Total		**956**	**1,149**	**1,378**	**1,690**	**1,790**	**1,861**	**2,090**	**2,090**

Germany (DE)

Species	Product	1997	1998	1999	2000	2001	2002	2003	2004*
Carps	Bighead Carp	12							
	Silver Carp	76							
	Common Carp	11,416	10,647	10,500	10,500	10,500	10,500	10,500	10,500
	Grass Carp	10							
European eels		150	150		150	150			
Trout	Large Rainbow Trout >1Kg	1,500	1,500	2,500	2,500	2,500	2,500	2,500	2,500
	White Portion Rainbow Trout	22,500	22,500	20,000	21,000	22,000	22,000	22,000	22,000
	Pink Portion Rainbow Trout	1,000	1,000	2,500	1,500	1,000	1,000	1,000	1,000
Grand total		**36,664**	**35,797**	**35,500**	**35,650**	**36,150**	**36,000**	**36,000**	**36,000**

Denmark (DK)

Species	Product	1997	1998	1999	2000	2001	2002	2003	2004*
Eels	European Eels	1,700	2,468						
	European Eels - 130/170g			2,415	2,400	1,900	2,100	1,900	1,900
	European Eels - >300g			285	275	200	200	150	150
Trout	Large Rainbow Trout >1Kg	7,000	7,500	7,500	7,500	7,000	6,500	13,000	13,000
	White Portion Rainbow Trout	28,300	29,000	23,000	23,000	24,000	24,000	22,000	22,000
	Pink Portion Rainbow Trout	1,000	3,000	7,000	7,000	7,000	7,000	5,000	5,000
Grand Total		**38,000**	**41,968**	**40,200**	**40,175**	**40,100**	**39,800**	**42,050**	**42,050**

Source: Federation of European Aquaculture Producers

* 2004 figures are provisional

United Kingdom (GB)

Species	Product	1997	1998	1999	2000	2001	2002	2003	2004*
Marine fish	Halibut				5	189	250	250	250
	Cod				16	41	50	50	50
Salmon	Atlantic Salmon 1-2 WFE	4,000	6,900	7,329	3,780	1,695	1,907	1,944	
	Atlantic Salmon 2-3 WFE	24,000	28,750	26,648	25,380	20,594	25,656	24,205	
	Atlantic Salmon 3-4 WFE	37,000	37,950	37,610	41,040	43,078	50,610	56,083	
	Atlantic Salmon 4-5 WFE	21,000	25,300	27,480	34,965	43,196	39,604	45,294	
	Atlantic Salmon 5-6 WFE	14,000	16,100	20,364	29,835	37,866	25,184	34,222	
Trout	Large rainbow trout >1kg	800	950	600	2,600	2,600	3,000	1,000	1000
	Pink Rainbow Trout >400 g			1,100					
	Rainbow Trout - Restocking	2,500	2,235	4,000	4,000	4,000	4,000	4,000	4,000
	Pink Portion Rainbow Trout	11,800	12,640	12,100	15,200	12,000	12,200	12,200	12,200
Grand Total		**115,100**	**130,825**	**137,231**	**156,821**	**165,259**	**162,461**	**179,248**	**n/a**

Spain (ES)

Species	Product	1997	1998	1999	2000	2001	2002	2003	2004*
Carps	Common Carp	50							
Eels	European Eels	266							
	European Eels - >300g		10	20	85	15	20		
Flatfish	Turbot	2,055	1,920	2,083	3,350	3,385	4,000	3,440	4,150
Salmon		1,100	300	300	300				
Sea Bass	European Seabass	829	1,408	1,670	2,300	1,950	3,180	4,530	6,200
Sea Bream	Gilthead Seabream	5,530	6,330	7,600	8,300	10,685	10,960	12,440	13,500
Trout	Large Rainbow Trout >1Kg	850	700	700	1,500	1,500	4,500	1,500	1,500
	White portion rainbow trout	10000	11000	12000	8,000	8,000	5,800	9,000	9,000
	Pink Portion Rainbow Trout	15,000	15,000	15,000	20,500	21,500	23,200	22,500	22,500
Grand Total		**35,680**	**36,668**	**39,373**	**44,335**	**47,035**	**51,660**	**53,410**	**56,850**

Finland (FI)

Species	Product	1997	1998	1999	2000	2001	2002	2004	2004*
Trout	Large rainbow trout >1kg	16,500	16,500	15,300	15,200	17,000	14,500	13,920	13,920
Grand Total		**16,500**	**16,500**	**15,300**	**15,200**	**17,000**	**14,500**	**13,920**	**13,920**

France (FR)

Species	Product	1997	1998	1999	2000	2001	2002	2003	2004*
Carps	Common Carp	5,500	6,000	6,000	6,000	6,000	6,000	6,000	6,000
Catfish	European Catfish	300							
Flatfish	Turbot	950	850	900	1,000	700	750	700	900
Salmon	Atlantic Salmon	0					5,000	8,000	10,000
Sea Basses	European Seabass	1,650	2,500	3,150	3,600	3,000	3,500	3,700	3,800
Sea Breams	Gilthead Seabream	1,000	1,250	1,000	1,400	1,700	1,500	1,100	1,300
Sturgeon	Sturgeon Juveniles		1	1	1	1			
	Sturgeon	70	60	110	130	150	150		
	Caviar - Sturgeon			3	5	5			
Trout	Large Rainbow Trout >1Kg	8,000	8,000	8,000	10,000	10,000	10,400	10,000	10,000
	Sea Trout	1,300	800	800					
	White Portion Rainbow Trout		2,500	2,000	2,500	2,500	2,500	2,000	2,500
	Arctic Char	60	60	60					
	Brook Trout	300	300	300					
	Pink Portion Rainbow Trout	42,000	40,000	35,000	35,000	35,000	30,000	25,000	25,000
Grand Total		**61,130**	**62,321**	**57,324**	**59,636**	**59,056**	**59,800**	**56,500**	**59,500**

Greece (GR)

Species	Product	1997	1998	1999	2000	2001	2002	2003	2004*
Carps	Common Carp	50	60						
Eels	European Eels	312	500	500					
	European Eels - 130/170g				250	550	500	500	500
	European Eels - >300g				50				
Sea Bass		12,000	17,000	20,000	23,000	24,000	28,000	26,000	27,000
Sea Bream	Gilthead Seabream	14,000	19,000	28,000	36,000	37,000	42,000	49,000	49,000
	Red Porgy			100					
	Sharp snout Seabream			1,000	0				
Trout	White Portion Rainbow Trout	2,322	2,334	2,800	2,500	3,000	3,000	3,000	3,000
Grand total		**28,684**	**38,894**	**52,400**	**61,800**	**64,550**	**73,500**	**78,500**	**79,500**

Ireland (IE)

Species	Product	1997	1998	1999	2000	2001	2002	2003	2004*
Flatfish	Turbot			8	12	15	30	50	50
Salmon	Atlantic Salmon 1-2 WFE	3,700	0	1,829	3,026	2,465	1,900	1,200	1,000
	Atlantic Salmon 2-3 WFE	5,500	0	3,657	5,874	5,465	4,390	3,520	3,000
	Atlantic Salmon 3-4 WFE	3,600	0	7,315	5,518	6,517	6,740	5,600	5,000
	Atlantic Salmon 4-5 WFE	1,400	0	3,657	1,780	4,875	4,831	4,000	3,400
	Atlantic Salmon 5-6 WFE	300	0	1,463	1,246	2,024	2,269	2,000	1,600
	Atlantic Salmon 6+ WFE			366	356	1,066	1,293	1,600	1
	Atlantic Salmon		15,200						
Trout	Large Rainbow Trout >1Kg	300	300	1,100	1,400	766	700	350	350
	Arctic Char				1	20	20	20	20
	Pink Portion Rainbow Trout	1,000	1,000	1,000	1,000	1,000	2,000	1,000	
Grand Total		**15,800**	**16,500**	**20,395**	**20,213**	**24,213**	**24,173**	**19,340**	**14,421**

Italy (IT)

Species	Product	1997	1998	1999	2000	2001	2002	2003	2004*
Carps	Common Carp	100	100	100					
Catfish	Channel Catfish	600	600	600					
Eels	European Eels	3,100							
	European Eels - >300g		1,900	1,900	1,700	1,500	700	700	600
Sea Bass	European Seabass	4,300	5,200	6,600	8,100	8,900	9,000	8,900	9,000
Sea Bream	Gilthead Seabream	3,500	4,600	4,800	6,000	6,800	8,000	7,800	8,500
	White Seabream		300	350	400	400	400	400	400
Sturgeon	Sturgeon	500	400	400					
Trout	Large Rainbow Trout >1Kg	1,000	1,000	800	800	800	600	600	600
	White portion rainbow trout	28,000	23,000	19200	19000	18800	17500	16200	15100
	Pink Portion Rainbow Trout	22,000	24,000	24,000	24,700	24,500	22,800	21,200	19,800
Grand Total		**63,100**	**61,100**	**58,750**	**60,700**	**61,700**	**59,000**	**55,800**	**54,000**

Netherlands (NL)

Species	Product	1997	1998	1999	2000	2001	2002	2004	2004*
Carps	Common Carp	80	80	80					
Catfish	African Catfish	1,000	1,650	2,200	2,500	2,500	2,000	3,500	4,000
Eels	European Eels	1,800	3,250						
	European Eels - 130/170g			3000	3250	3250	3450	3150	3375
	European Eels - >300g			800	750	750	750	1,050	1,125
Flatfish	Turbot							75	75
Tilapias	Tilapia							300	600
Trout	White Portion Rainbow Trout	200	200	200	200	200	200	200	200
Grand Total		**3,080**	**5,180**	**6,280**	**6,700**	**6,700**	**6,400**	**8,275**	**9,375**

Poland (PL)

Species	Product	1997	1998	1999	2000	2001	2002	2004	2004*
Carps	Silver Carp			350					
	Common Carp	22,500	19,400	19,300	22,600	21,500	18,000	19,200	22,000
	Grass Carp	1,500	1,500	350	1,500	1,500	1,500	1,200	1,200
Catfish	African Catfish			100	150	200	200	300	350
	European Catfish				50	70			
Sturgeon				30	130	40	50	200	250
Trout	White Portion Rainbow Trout	6,500	9,000	9,000	10,160	11,000	11,000	13,000	13,500
Grand total		**30,500**	**29,900**	**29,130**	**34,590**	**34,310**	**30,750**	**33,900**	**37,300**

Portugal (PT)

Species	Product	1997	1998	1999	2000	2001	2002	2003	2004*
Flatfish	Turbot		265	475	510	540	540	540	540
Sea Bass	European Seabass	902	1,000	849	1,080	700	800	1,500	1,500
Sea Bream	Gilthead Seabream	1,700	1,900	1,595	2,060	2,000	2,200	2,500	2,500
Eels	European Eel	200	200	200	200	200			
Trout	Pink Rainbow trout	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500
Grand Total		**4,302**	**4,865**	**4,619**	**5,350**	**4,940**	**5,040**	**6,040**	**6,040**

Sweden (SE)

Species	Product	1997	1998	1999	2000	2001	2002	2003	2004*
Eels	European Eels					230	230	230	230
Salmon		100	3						
Trout	Large rainbow trout >1kg	4875	6500	7250	7000	7000	6500	3000	3000
	White Portion Rainbow Trout	200	200						
	Arctic Char	183	200	350	500	500	350	350	350
Grand total		**5,358**	**6,903**	**7,600**	**7,500**	**7,730**	**7,080**	**3,580**	**3,580**

Table 50: Summary of Pressure Attributes

Criteria	Scale	Attributes by pressure		
		Habitat modification	**Change in dissolved oxygen**	**Landscape and seascape modifications**
Magnitude	0	No measurable impact will occur	No change in dO	No alteration to landscape / seascape vista
	1	The impact will be measurable but of limited proportion, degree or extent; adverse impact will not represent a significant risk to the environmental feature	10% decrease below background levels and sufficient to be noticed	Minor alteration to landscape / seascape vista (less than a 10% change from low level or high level viewpoint)
	2	Impact on a noticeable proportion of an environmental feature; adverse impacts will represent a risk to the feature; beneficial impacts could result in enhancement	50% decrease below background levels and sufficient to be nuisance. Concentration falls below regional EQS of 4-6 mg/L	Moderate alteration to landscape / seascape vista (less than a 30% change from low level or high level viewpoint)
	3	Substantial impact on an environmental feature; adverse impacts likely to result in loss of integrity of the feature; beneficial impacts likely to result in addition to or enhancement of the feature	Anoxic conditions at the benthic boundary layer	Major alteration to landscape / seascape vista (more than 50% change from low level or high level viewpoint)
Significance	0	No measurable significance	No perceived change in dO	No perceived change in landscape / seascape appearance
	1	Direct or indirect impact which will cause only limited modification but not direct loss, no impact on integrity of the site (alone or in combination)	Just noticeable change to cause stress	Only noticeable change at a very local level or from one particular vista
	2	Direct or indirect impact that could result in an impact on the integrity of the site (species or habitats) (alone or in combination)	Important change to cause impoverished communities	Important change to the visual assessment of the area
	3	Direct or indirect impact that could result in a significant impact on the integrity of the site (species or habitats) (alone or in combination)	Sufficient change to cause azoic conditions	Sufficient change to the landscape/seascape to be of major significance.
Duration	0	Duration of impact too short to result in measurable change	No change	No change in landscape / seascape vista over the life span of the development
	1	Effects last during construction period	Occasional decrease in dO	Minor change in landscape / seascape vista over the life span of the development
	2	The effects will last during the period of operation but without residual damage	Seasonal/periodical decrease in dO	Moderate change in landscape / seascape vista over the life span of the development
	3	The effects of the impact will exceed that of the operation/activity	Permanent anoxia	Major change in landscape / seascape vista over the life span of the development

Distribution	0	Undetectable change	Undetectable change in dO	No visual spatial impact of development
	1	Impact detectable within footprint of the site but not deemed significant impact on the integrity of the features or site integrity.	Decrease detectable only at local level i.e. 10m from the edge of the farm	Minor visual spatial impact of development
	2	Impact detectable within the footprint of the site or externally to the site footprint and could impact the integrity of the features or site integrity.	Decrease detectable at meso-scales e.g. 5 km from the farm	Moderate visual spatial impact of development
	3	Impact extending beyond confines of the site and will significantly affect the features and site integrity.	Decrease detectable at the level of a water body i.e. tens of km from the farm	Major visual spatial impact of development

Criteria	Scale	Attributes by pressure		
		Changes in coastal processes	**Disturbance**	**Predator control**
Magnitude	0	No change in sediment drift rates/current speeds/hydrodynamics	No perceived visual or auditory impact above background levels	Predator problem insignificant or ignored.
	1	Minor alteration to sediment drift rates/current speeds/hydrodynamics (less than a 10% change)	Sound levels 5dB above background levels and sufficient to be noticed	Passive barriers in place only
	2	Moderate alteration to sediment drift rates/current speeds/hydrodynamics (less than a 30% change)	Sound levels over 10dB above background levels and sufficient to be a nuisance	Active deterrent systems (ADD or bird scarers) routinely used.
	3	Major alteration to sediment drift rates/current speeds/hydrodynamics (more than 50% change)	Sound levels over a) 85 dBA daily exposure [24], and b) 135 dBA peak sound levels	Predators routinely trapped or killed
Significance	0	No change to sediment budget/coastal hydrodynamics of the area	No perceived visual or auditory impact above background levels	Insignificant impact
	1	Only marginal change to the sediment budget/ coastal hydrodynamics of the area	Sound level causes temporary avoidance behaviour	Short-term behaviour patterns may change but overall behaviour unchanged.
	2	Important change to sediment budget/ coastal hydrodynamics of the area.	Sound level causes immediate and permanent avoidance behaviour	Significant seasonal changes to life strategy and behaviour e.g. impaired breeding success
	3	Sufficient change to the sediment budget/coastal hydrodynamics to be of major significance	Sufficient sound level to cause severe auditory trauma and / or psychological damage	Profound and long-term changes to life strategy and behaviour

[24] The dBA Lex term means the total exposure to noise in dBA, averaged over the entire workday and adjusted to an equivalent 8-hour exposure.

Criteria	Scale	Attributes by pressure		
		Changes in coastal processes	Disturbance	Predator control
Duration	0	No short term or long term change in sediment budget/ coastal hydrodynamics over the life span of the development	No perceived visual or auditory impact above background levels	Insignificant impact
	1	Minor short term or long term change in sediment budget/ coastal hydrodynamics over the life span of the development (impact is reversible)	Continuous background hum	Predators and non-predators show temporary (<5 days) avoidance behaviour
	2	Moderate short term or long term change in sediment budget/ coastal hydrodynamics over the life span of the development (impact is possibly not reversible) over the life span of the development	Regular percussive sounds	Predators and non-predators show long-term (seasonal) avoidance behaviour
	3	Major short term and long term change in sediment budget/ coastal hydrodynamics over the life span of the development (impact is not reversible) over the life span of the development	Irregular percussive sounds	Predator and non-predator populations permanently evicted from area.
Distribution	0	No hydrodynamic spatial impact of development (beyond limits of immediate farmed area)	Inaudible outside immediate threshold of the farm site	Undetectable outside immediate threshold of the farm site
	1	Minor hydrodynamic spatial impact of development (within limits of immediate farmed area only)	Only audible within 400 m of the farm boundary	Detectible within 400 m of the farm boundary
	2	Moderate hydrodynamic spatial impact of development (within adjacent region only)	Audible outside 400 m of the farm boundary but unlikely to cause disturbance	Detectible outside 400 m of the farm boundary but unlikely to cause disturbance
	3	Major hydrodynamic spatial impact of development (within wider coastal cell area – kilometres of impact)	Audible outside 400 m of the farm boundary and likely to cause disturbance	Detectible outside 400 m of the farm boundary and likely to cause disturbance

Criteria	Scale	Attributes by pressure		
		Sedimentation	**Chemical use**	**Transmission of disease & parasites**
Magnitude	0	No measurable sig. increase in allochthonous sediment deposition/organic matter (OM) beneath cages/raft.	No use	No disease or parasite present
	1	Moderate sediment deposition / organic matter (OM).	Used in small amounts	Disease or parasite present but not spreading to the environment
	2	Significant sediment deposition. Enhanced organic carbon (OC) deposition greater than 0.70 kgC/m^2 y. Above this critical value, it has been shown that the infaunal diversity of sediments is reduced, and the seabed can be considered 'degraded' (ICES, 2003).	Used in large amounts but within the legal limits/producer recommendations	Disease or parasite spread to the environment, may affect individuals but not wild population dynamics
	3	Anoxic conditions at the benthic boundary layer. Substantially enhanced OC deposition which clearly accumulates in the sediment.	Used in large amounts above the legal limits/producer recommendations	Disease or parasite spread to the environment and affecting wild population dynamics
Significance	0	No measurable impact on biota (AMBI <1.2, Muxika et al., 2005) (RPD >5cm but depends on sediment type; Nilsson & Rosenberg, 1997). ITI, AMBI, RPD apply only in soft sediments. No measurable loss of habitat.	Insignificant impact	Insignificant impact
	1	Observed changes in behaviour of marine animals. Minimum impact on benthic communities, ITI, AMBI, other benthic index threshold (e.g. ITI >60, AMBI: 1.3-3.3). Decrease in depth of RPD layer in relation to reference (e.g. RPD: 5 – 3.5cm) or in redox potential (Eh). Benthic primary productivity moderately reduced. Limited loss of habitat.	Reversible changes in physiology and/or behaviour	Changes in physiology and/or behaviour of wildlife
	2	Medium impact on benthic communities, evidence of organic loading (e.g. ITI: 60-30 , AMBI: 3.4-4.3) Decrease in depth of RPD layer in relation to reference (e.g. RPD: 3.5 – 2cm)) or in redox potential. Major loss of habitat.	Irreversible/sub-lethal changes in physiology and/or behaviour	Lethal/sub-lethal effects on individuals without significant effects on populations

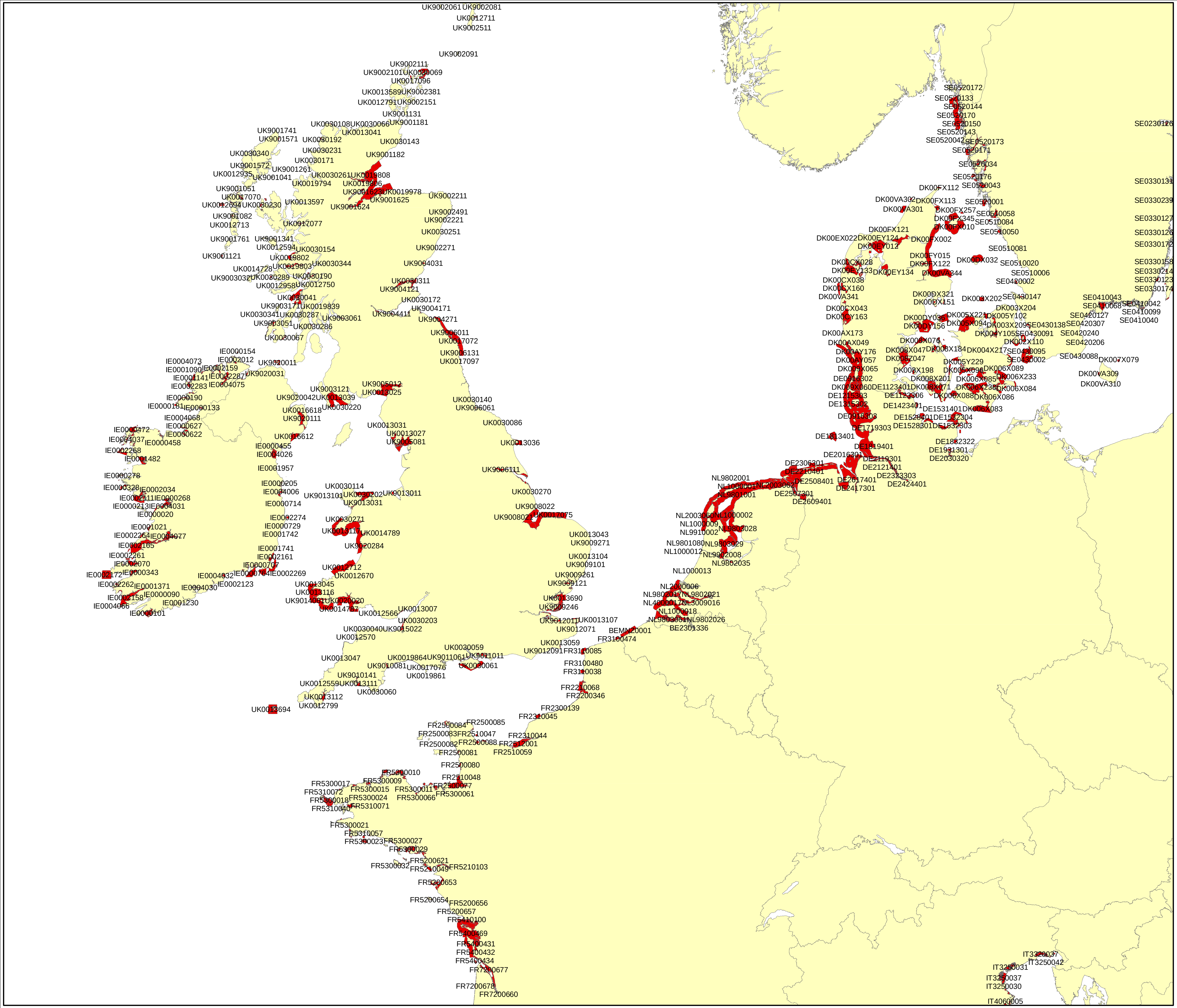
Criteria	Scale	Attributes by pressure		
		Sedimentation	**Chemical use**	**Transmission of disease & parasites**
	3	Severe/total impoverishment of benthic community. Mass mortalities, overload OM; presence of H_2S, threshold benthic index indicates serious impairity (e.g. ITI <30, AMBI: >4.3) Decrease in depth of RPD layer in relation to reference or in redox potential. Benthic primary productivity seriously reduced Total loss of habitat.	Lethal effects	Lethal/sub-lethal effects on individuals with significant effects on populations
Duration	0	No sig increase in sediment deposition, or measurable decrease in benthic DO, benthic index.	Insignificant impact	Insignificant impact
	1	Statistically sig increase in sediment deposition, or measurable decrease in benthic DO, benthic index. Rapid recovery (within weeks). Moderate short term impact.	Short-term disappearance/detoxification/ removal from the environment (weeks)	Short-term disappearance/eradication/removal from the environment
	2	Stat sig increase in sediment deposition, or measurable decrease in benthic DO; recovery within months. Moderate to large long term impact, slow recovery.	Long-term disappearance/detoxification/ removal from the environment (months)	Long-term disappearance/eradication/removal from the environment
	3	Stat sig increase in sediment deposition, or measurable decrease in benthic DO recovery within years.	Permanent occurrence in the environment	Permanent occurrence in the environment
Distribution	0	Undetectable outside farm. Impact insignificant in scale	Insignificant impact	
	1	Stat sig increase in sediment deposition, or measurable decrease in benthic DO or in benthic index value detectable in zone A around the farm.	Small spatial scale (meters) from the discharge point	
	2	Stat sig increase in sediment deposition, or measurable decrease in benthic DO or in benthic index value on water body (zone B).	Medium spatial scale (hectometres) from the discharge point	
	3	Stat sig increase in sediment deposition, or measurable decrease in benthic DO or in benthic index value in at least some parts of the regional scale (zone C)	Large spatial scale (kilometres) from the discharge point	

Criteria	Scale	Attributes by pressure		
		Nutrient enrichment of water column	**Inter-breeding**	**Use of exotic species**
Magnitude	0	Undetectable nutrient enrichment	Low proportion of farmed to wild fish in the population (< 10%)	No known alien species introduced
	1	Increase in concentration over background by 50%	Proportion of farmed to wild fish in the population sufficient for introgression (10-40%)	Low number of individuals introduced (<100)
	2	Increase in concentration over background by 100%	Proportion of farmed to wild fish in the population capable of producing a high evolutionary force (40-80%)	High number of individuals introduced (>100)
	3	Increase in concentration over background by 500%	Very high proportion of farmed to wild fish in the population (80-100%)	Very high number of individuals introduced (>1000)
Significance	0	No detectable change in chla	Observed reduction of wild fish is inexistent or insignificant (< 20%)	Observed reduction of native species following the introduction inexistent or insignificant (< 20%)
	1	10% increase in chla	Observed reduction of 20% of wild fish over the last 10 yrs or 3 generations (whichever is the longest) (Vulnerable)	Observed reduction of 20% of at least one native species over the last 10 yrs or 3 generations (whichever is the longest) following the introduction (Vulnerable)
	2	100% increase in chla	Observed reduction of 50% of wild fish over the last 10 yrs or 3 generations (whichever is the longest) (Endangered)	Observed reduction of 50% of at least one native species over the last 10 yrs or 3 generations (whichever is the longest) following the introduction (Endangered)
	3	Increase in chla sufficient to cause anoxic conditions on the sea bed after sedimentation of phytoplankton	Observed reduction of 80% of wild fish over the last 10 yrs or 3 generations (whichever is the longest) (Critically Endangered)	Observed reduction of 80% of at least one native species over the last 10 yrs or 3 generations (whichever is the longest) following the introduction (Critically Endangered)
Duration	0	Undetectable at any time scale	Occasional cultured fish escapes (one every 5 years)	No known alien species escapes
	1	Detectable only for some hours (diel cycle)	Regular but infrequent cultured fish escapes (one per year)	Occasional alien species escapes (one every 5 years)
	2	Detectable for a small number of days (during adverse weather/circulation conditions)	Frequent cultured fish escapes (more then one per year)	Regular but infrequent alien species escapes (one per year)
	3	Detectable for long periods (e.g. during high feeding season)	Frequent cultured fish escapes during springtime (more then one per year)	Frequent alien species escapes (more then one per year)

Criteria	Scale	Attributes by pressure		
		Nutrient enrichment of water column	Inter-breeding	Use of exotic species
Distribution	0	Undetectable at the fish farm site	Inter-breeding effects a wild population with an extent of occurrence estimated to be > 20.000 km² or area of occupancy estimated to be > 2000 km²	No alien species ever reported in the wild or alien species reported only at local level (1 km range) as a result of the past introduction of a poor coloniser
	1	Detectable at the close vicinity of the farm (<25 m) within a single diurnal tidal cycle	Inter-breeding effects a wild population with an extent of occurrence estimated to be < 20.000 km² or area of occupancy estimated to be < 2000 km²	Alien species reported only at local level (<1 km) as a result of the recent introduction of a poor coloniser
	2	Detectable at meso-scales (1 km from farming zone) within 10 days	Inter-breeding effects a wild population with extent of occurrence estimated to be < 5000 km² or area of occupancy estimated to be < 500 km²	Alien species reported at the local level (<1 km) as a result of the recent introduction of a successful coloniser
	3	Detectable throughout the water body (e.g. bay, fjord etc) over 10-100 days	Inter-breeding effects a wild population with an extent of occurrence estimated to be < 100 km² or area of occupancy estimated to be < 10 km²	Alien species reported at water body or regional level (>10 km) as a result of the past introduction of a successful coloniser

Appendix D: Natura 2000 Areas in the EU

European Wide Natura 2000 Regions (4 maps): showing the distribution of Natura 2000 sites around the coastal NUTS 2 regions. For each Natura 2000 area the unique identifier is displayed, thereby providing a means of cross referencing the spatial data with the appropriate support information.



ATKINS

Legend

N2K Regions

Europe

Non-Europe

Rev	Description	By	Date	Chk'd	Auth

Description	By	Date	Authorised

ATKINS

Chadwick House
Birchwood Park
Warrington
WA3 6AE
Tel. (01925) 238000
Fax. (01925) 238500

Client

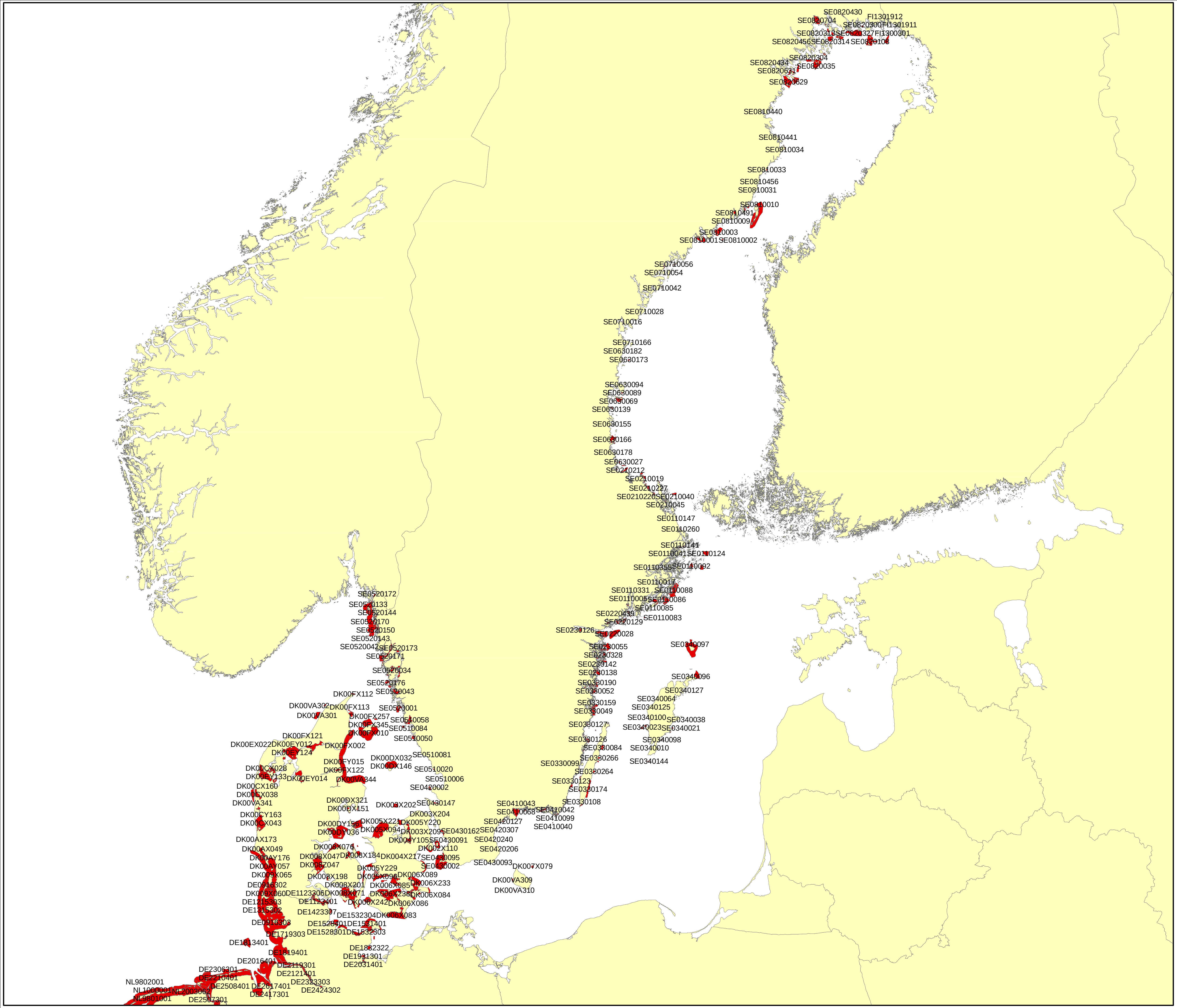
Project

Title

N2K Regions (1 of 4)

Scale	Drawn	Checked	Authorised
1:10,000,000 at A3	CG		
	Date 14/11/05	Date	Date

Drawing Number



ATKINS

Legend

N2K Regions	
Europe	
Non-Europe	

Rev	Description	By	Date	Chk'd	Auth

Description	By	Date	Authorised

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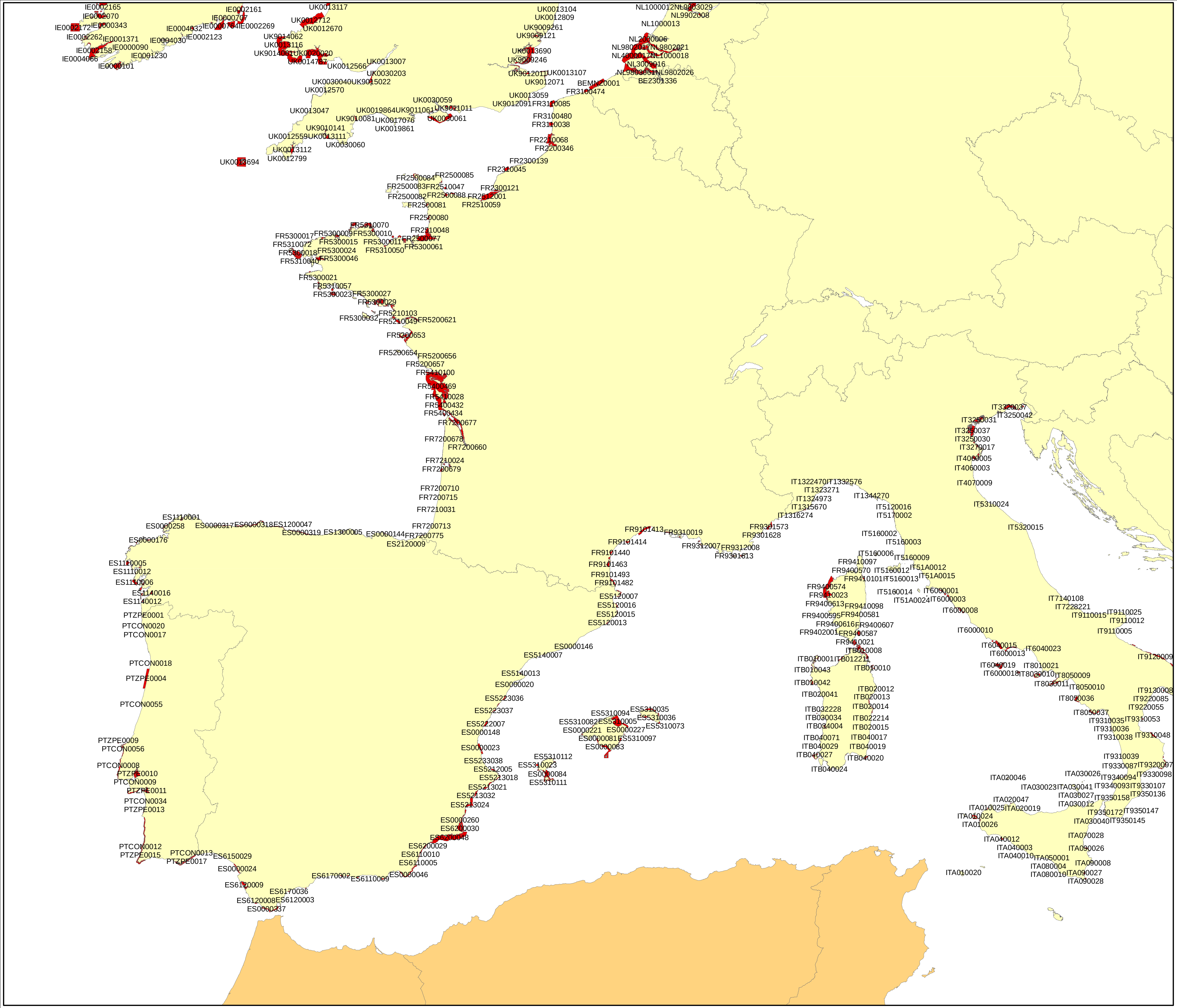
Title

N2K Regions (4 of 4)

Scale	Drawn	Checked	Authorised
1:10,000,000 at A3	CG		
	Date 14/11/05	Date	Date

Drawing Number



Legend

- N2K Regions
- Europe
- Non-Europe

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N2K Regions (2 of 4)

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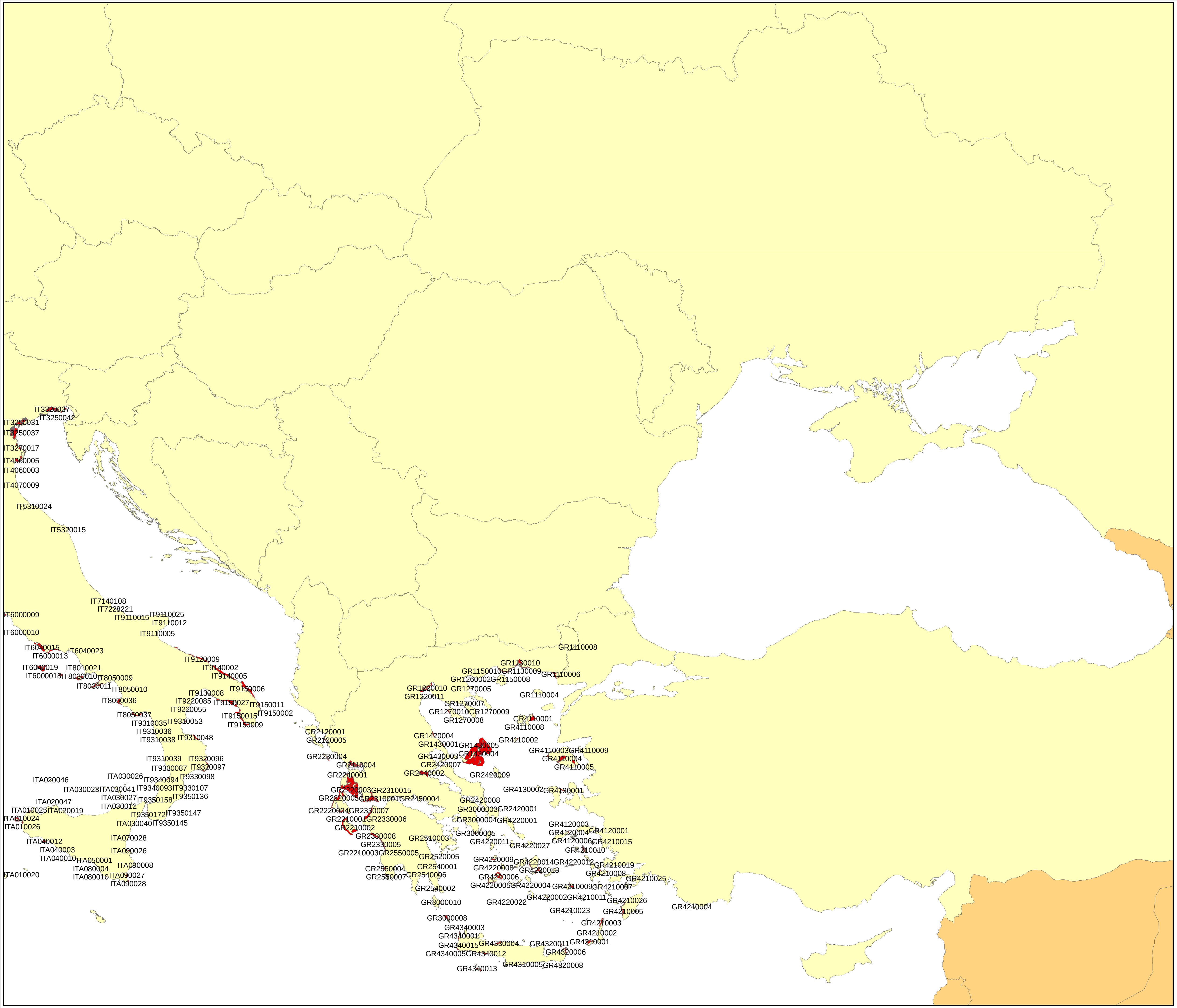
	Date 14/11/05	Date	Date

Drawing Number



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Legend

- N2K Regions
- Europe
- Non-Europe

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Description	By	Date	Authorised

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Title

N2K Regions (3 of 4)

Scale	Drawn	Checked	Authorised
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	Date 14/11/05	Date	Date

Drawing Number

Appendix E: Spatial Representation of Finfish Culture in the EU

A. European Wide Fish Production, 2003 (4 maps): As in the shellfish maps each aquaculture region displays the quantity of fish being produced and the proportion of fish types being farmed.

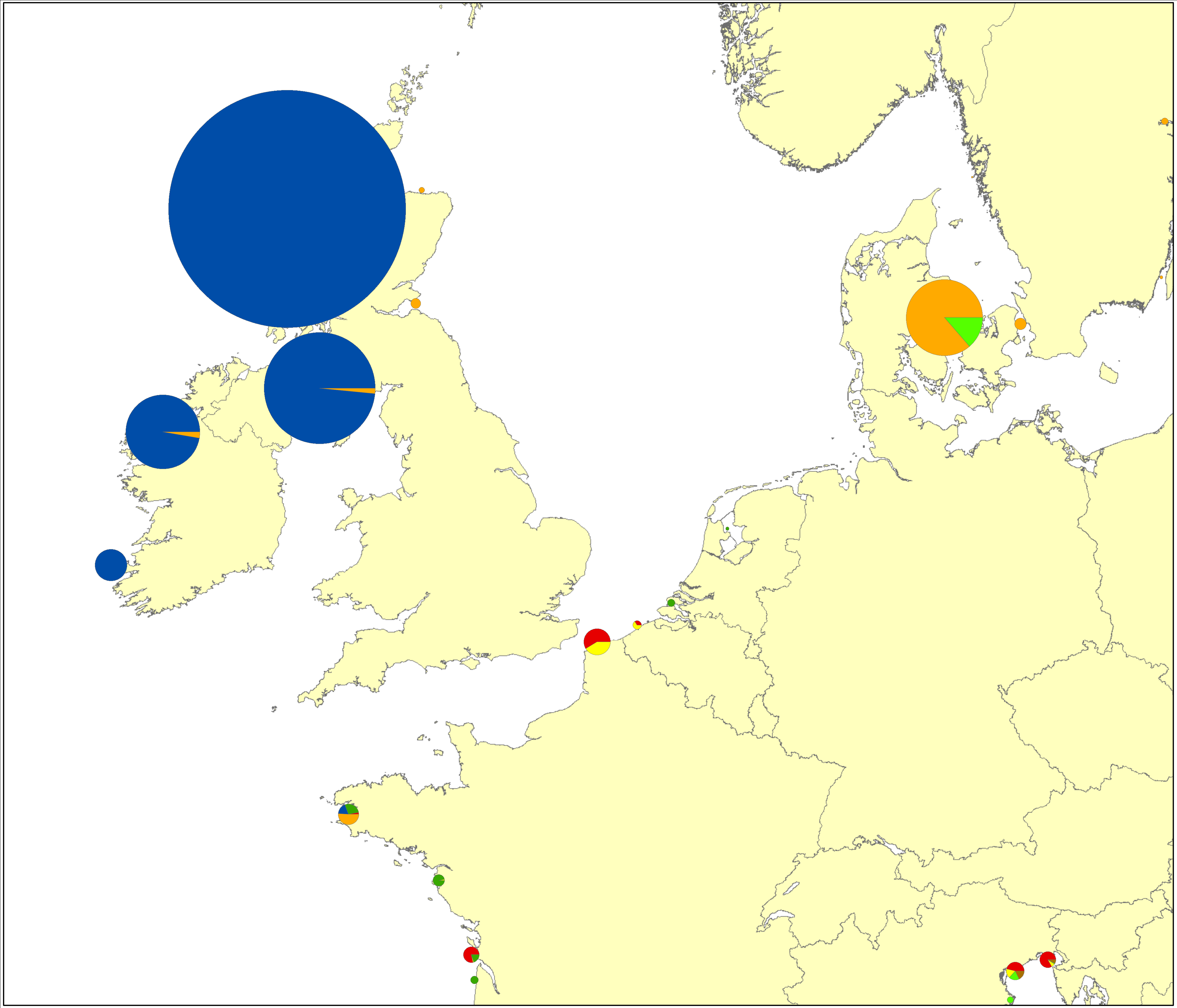
B. Regional maps: Maps showing aquaculture production for the top four fish producing NUTS 2 regions

Top 5 fish-producing NUTS 2 regions:

1. Highlands and Islands
2. South West Scotland
3. Sterea Ellada
4. Denmark

For each region two maps are produced showing (i) Natura 2000 areas and (ii) other conservation areas. For both map types, each designated area is labelled with either a unique reference number (for Natura 2000) or a site name (for other conservation designations.) In addition to the environmental information a table is displayed in each map detailing aquaculture production figures and techniques for that region.

Source: Spatial Applications Data, Leuven & project-derived production data



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Legend

Production mt/yr (2003)

4,100

- SEA BASS
- SEA BREAM
- GADOIDS
- FLATFISH
- SALMON
- SEA GROWN TROUT
- EELS
- TUNA
- OTHER FINFISH
- Europe
- Non-Europe

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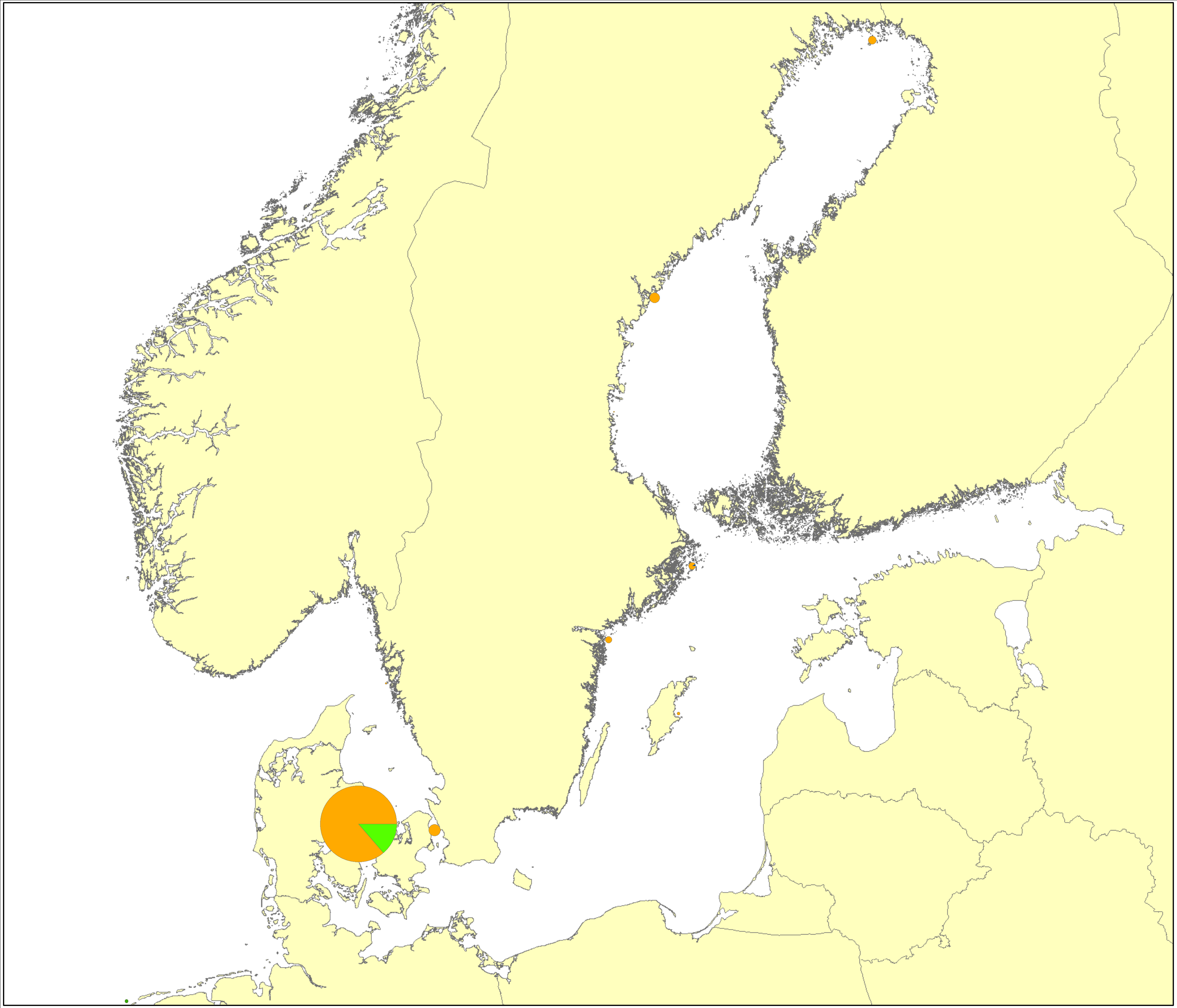
Title

Fish Production (1 of 4)

Scale	Drawn	Checked	Authorised
1:10,000,000 at A3	CG		
	Date 13/10/05	Date	Date

Drawing Number



ATKINS

Legend

Production mt/yr (2003)

4,100

- SEA BASS
- SEA BREAM
- GADOIDS
- FLATFISH
- SALMON
- SEA GROWN TROUT
- EELS
- TUNA
- OTHER FINFISH
- Europe
- Non-Europe

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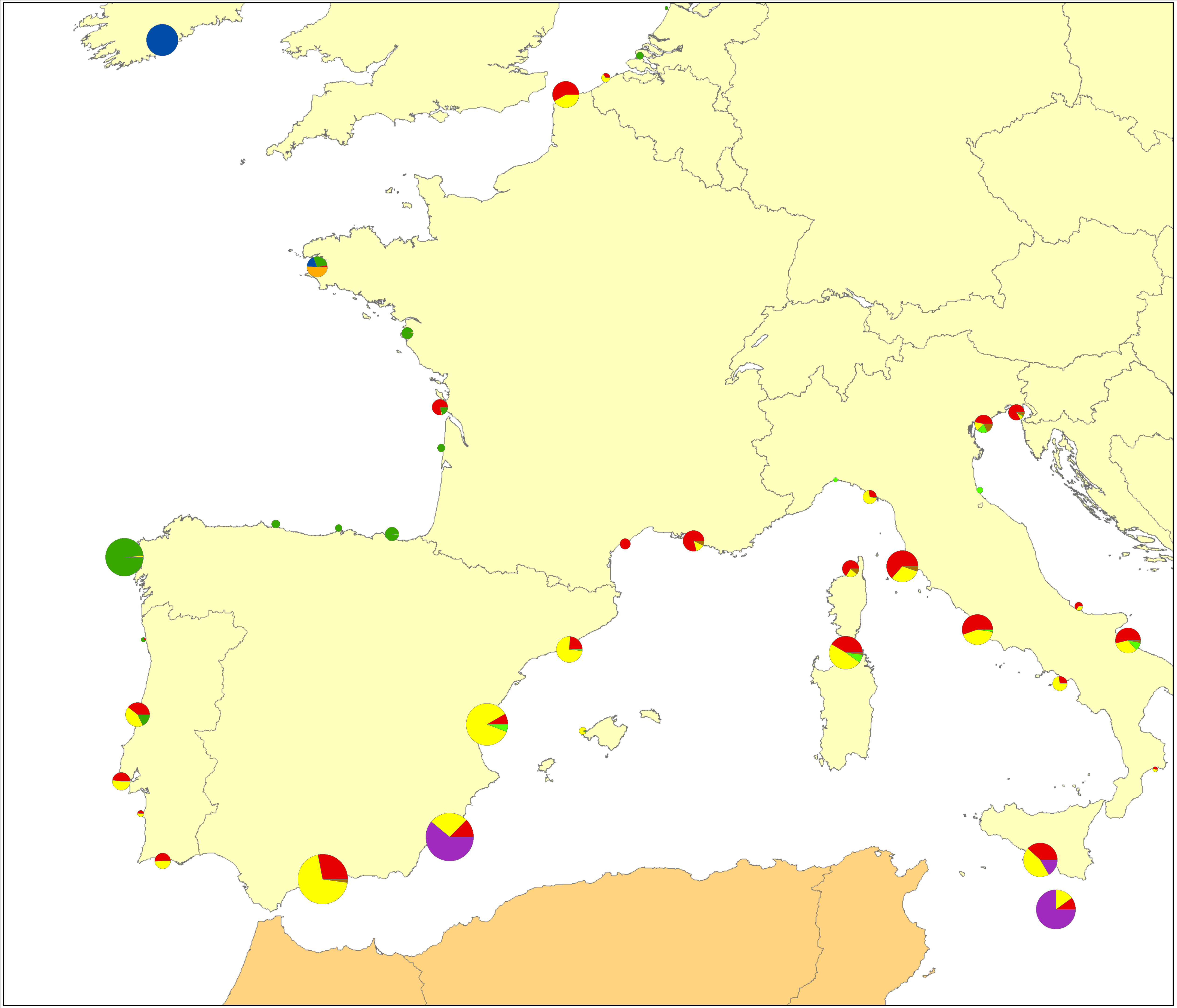
Fish Production (4 of 4)

Scale	Drawn	Checked	Authorised
1:10,000,000 at A3	CG		
	Date 13/10/05	Date	Date

Drawing Number



ATKINS

Legend

Production mt/yr (2003)

4,100

- SEA BASS
- SEA BREAM
- GADOIDS
- FLATFISH
- SALMON
- SEA GROWN TROUT
- EELS
- TUNA
- OTHER FINFISH
- Europe
- Non-Europe

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Fish Production (2 of 4)

Scale	Drawn	Checked	Authorised
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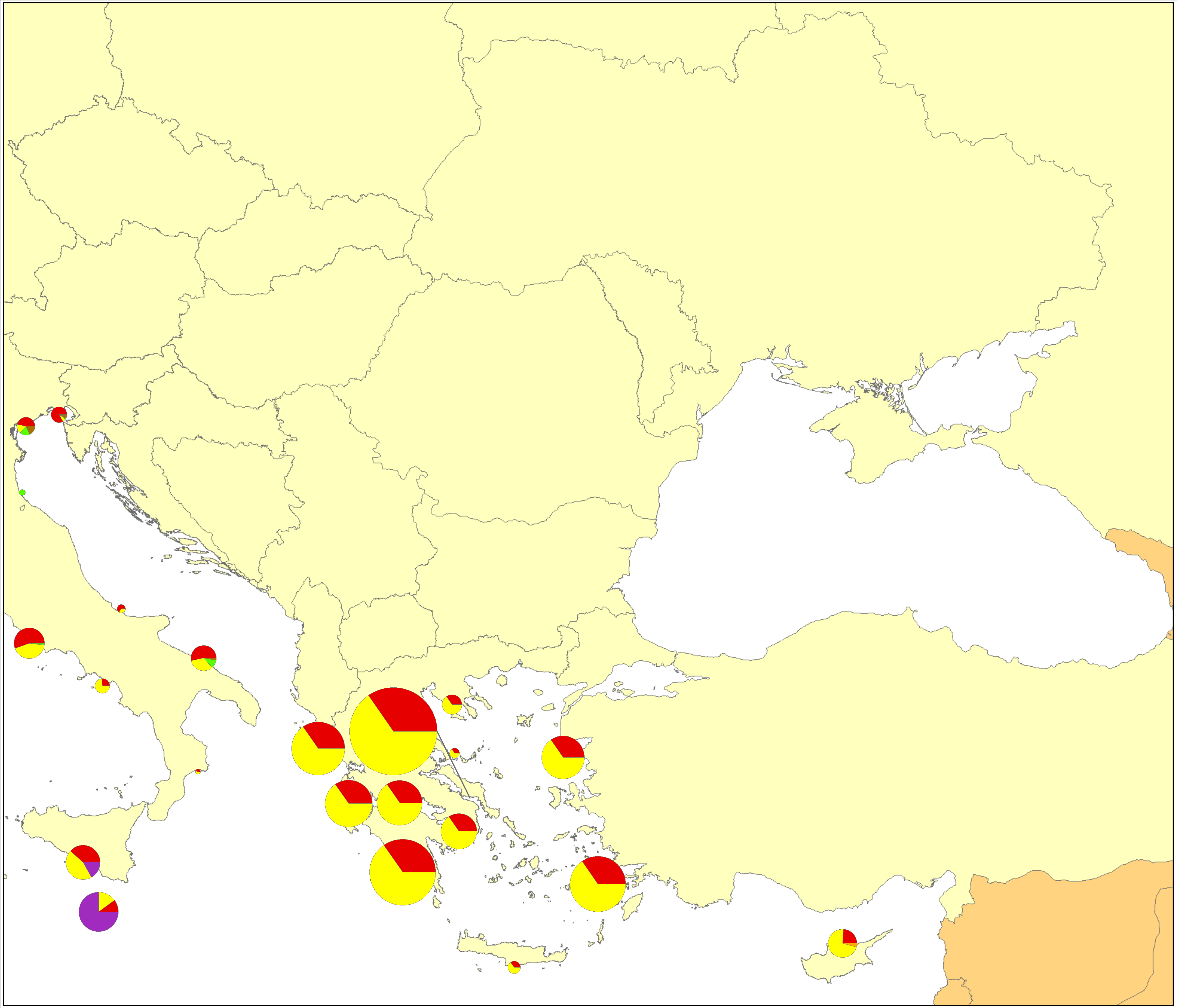
	Date 13/10/05	Date	Date

Drawing Number



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Legend

Production mt/yr (2003)

4,100

- SEA BASS
- SEA BREAM
- GADOIDS
- FLATFISH
- SALMON
- SEA GROWN TROUT
- EELS
- TUNA
- OTHER FINFISH
- Europe
- Non-Europe

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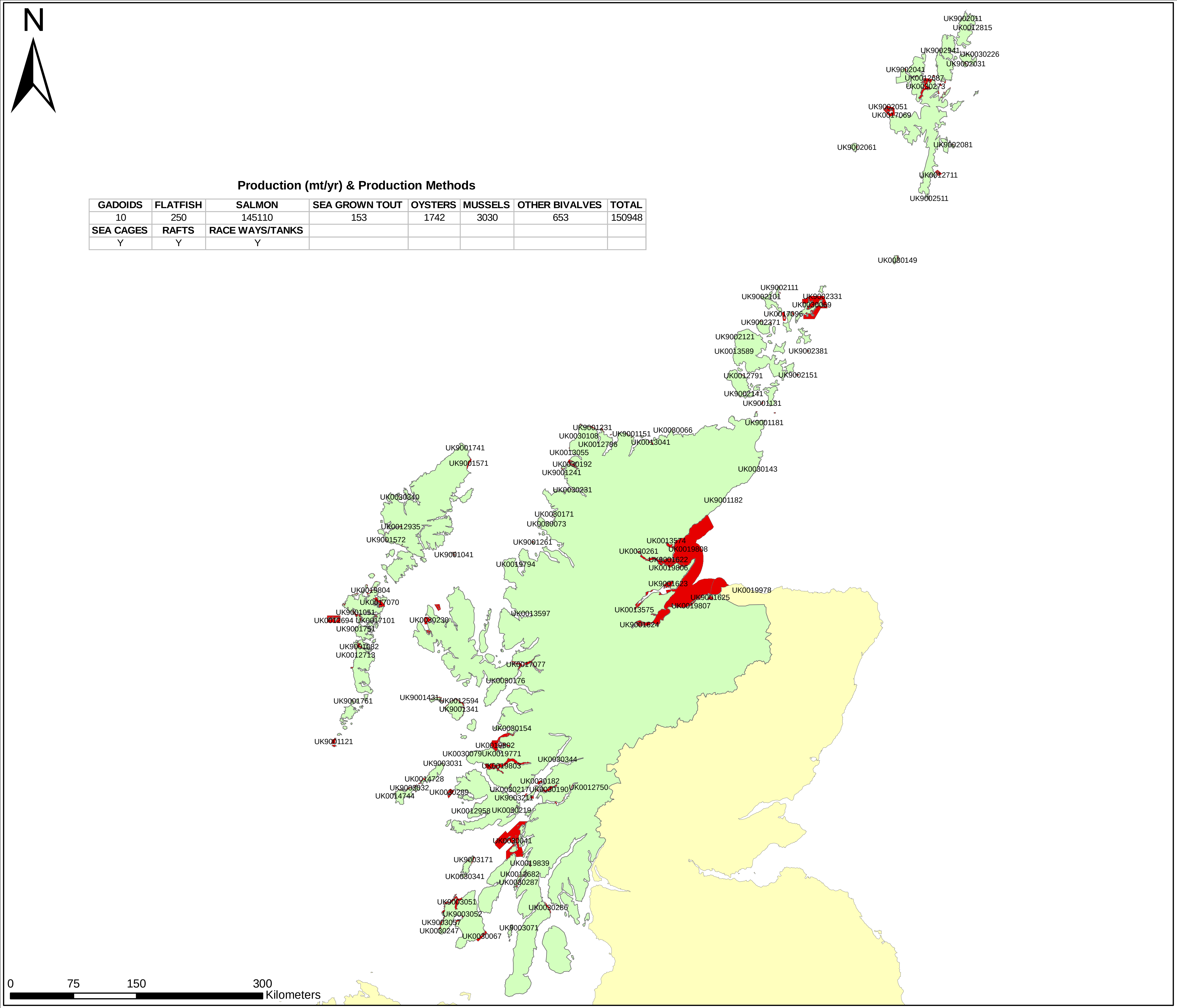
Fish Production (3 of 4)

Scale	Drawn	Checked	Authorised
1:10,000,000 at A3	CG		
	Date 13/10/05	Date	Date

Drawing Number

Production (mt/yr) & Production Methods

GADOIDS	FLATFISH	SALMON	SEA GROWN TOUT	OYSTERS	MUSSELS	OTHER BIVALVES	TOTAL
10	250	145110	153	1742	3030	653	150948
SEA CAGES	**RAFTS**	**RACE WAYS/TANKS**					
Y	Y	Y					



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Legend

- N2K Regions
- Highlands & Islands
- Europe

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Title
Highlands & Islands N2K Regions

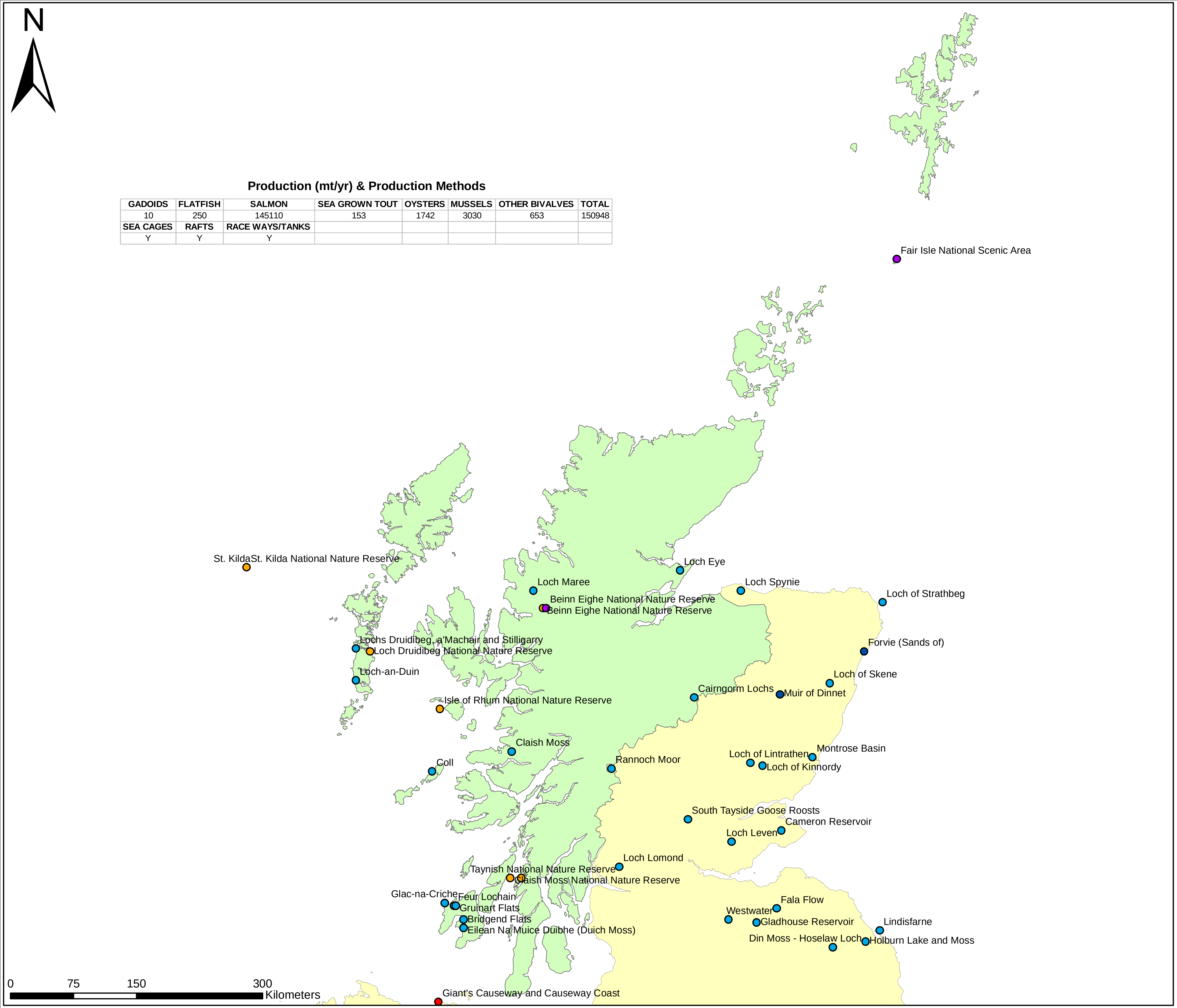
Scale	Drawn	Checked	Authorised
1:4,200,000 at A3	CG		
	Date 09/11/05	Date	Date

Drawing Number

Highlands & Islands Conservation Areas

Production (mt/yr) & Production Methods

GADOIDS	FLATFISH	SALMON	SEA GROWN TOUT	OYSTERS	MUSSELS	OTHER BIVALVES	TOTAL
10	250	145110	153	1742	3030	653	150948
SEA CAGES	**RAFTS**	**RACE WAYS/TANKS**					
Y	Y	Y					



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Legend

- Barcelona Convention SPA
- CoE Biogenetic Reserves
- CoE EuroDiploma
- Helsinki Convention Sites
- Ramsar Sites
- Unesco BioSphere Reserves
- World Heritige Sites
- Highlands & Islands
- Europe

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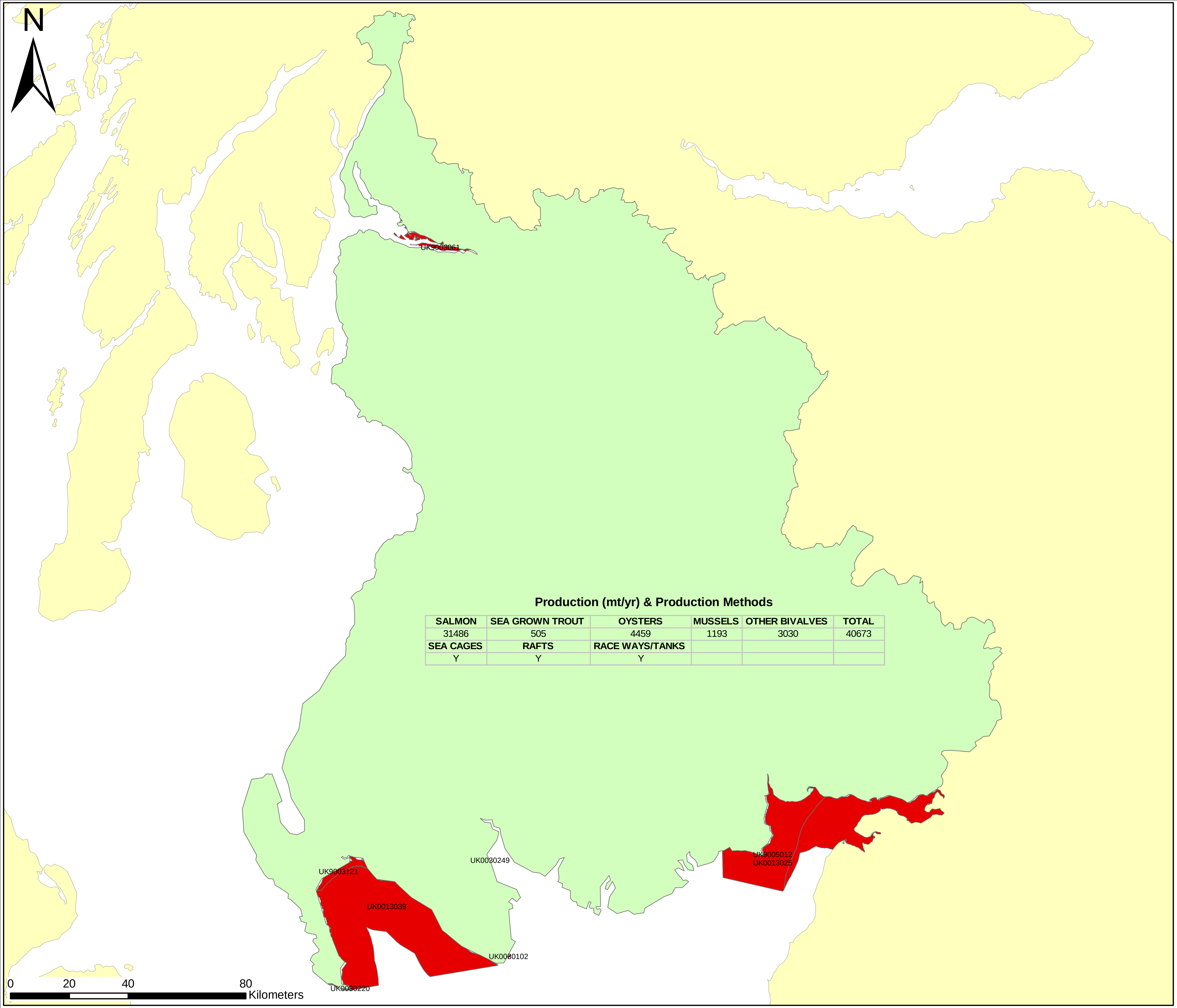
Title

Highlands & Islands Conservation Areas

Scale	Drawn	Checked	Authorised
1:4,200,000 at A3	CG		
	Date 09/11/05	Date	Date

Drawing Number



Production (mt/yr) & Production Methods

SALMON	SEA GROWN TROUT	OYSTERS	MUSSELS	OTHER BIVALVES	TOTAL
31486	505	4459	1193	3030	40673
SEA CAGES	RAFTS	RACE WAYS/TANKS			
Y	Y	Y			

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Legend

- N2K Regions
- SW Scotland
- Europe

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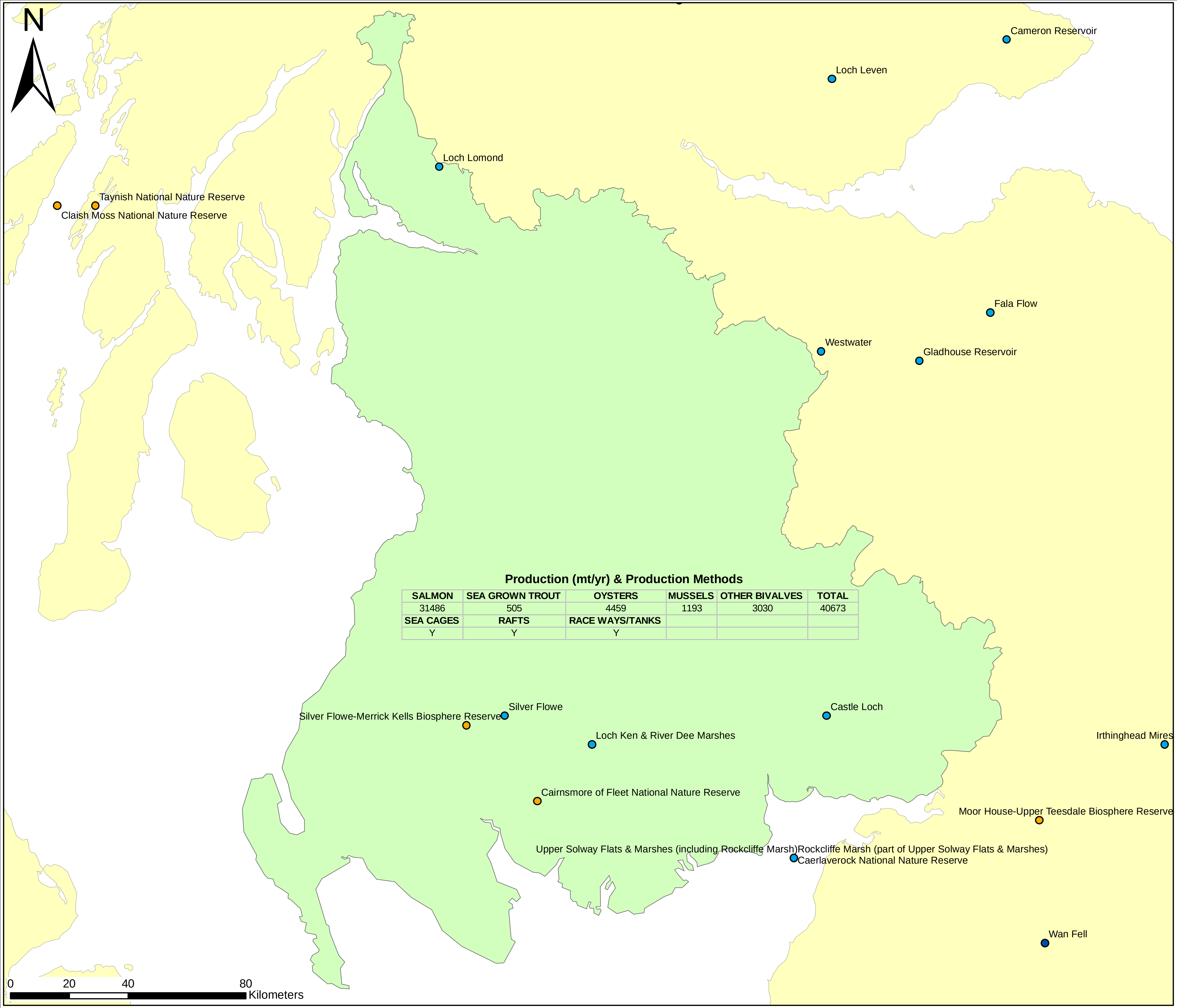
Title
South Western Scotland N2K Regions

Scale	Drawn	Checked	Authorised
1:1,200,000 at A3	CG		
	Date 09/11/05	Date	Date

Drawing Number



Production (mt/yr) & Production Methods

SALMON	SEA GROWN TROUT	OYSTERS	MUSSELS	OTHER BIVALVES	TOTAL
31486	505	4459	1193	3030	40673
SEA CAGES	**RAFTS**	**RACE WAYS/TANKS**			
Y	Y	Y			

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Legend

- Barcelona Convention SPA
- CoE Biogenetic Reserves
- CoE EuroDiploma
- Helsinki Convention Sites
- Ramsar Sites
- Unesco BioSphere Reserves
- World Heritige Sites
- SW Scotland
- Europe

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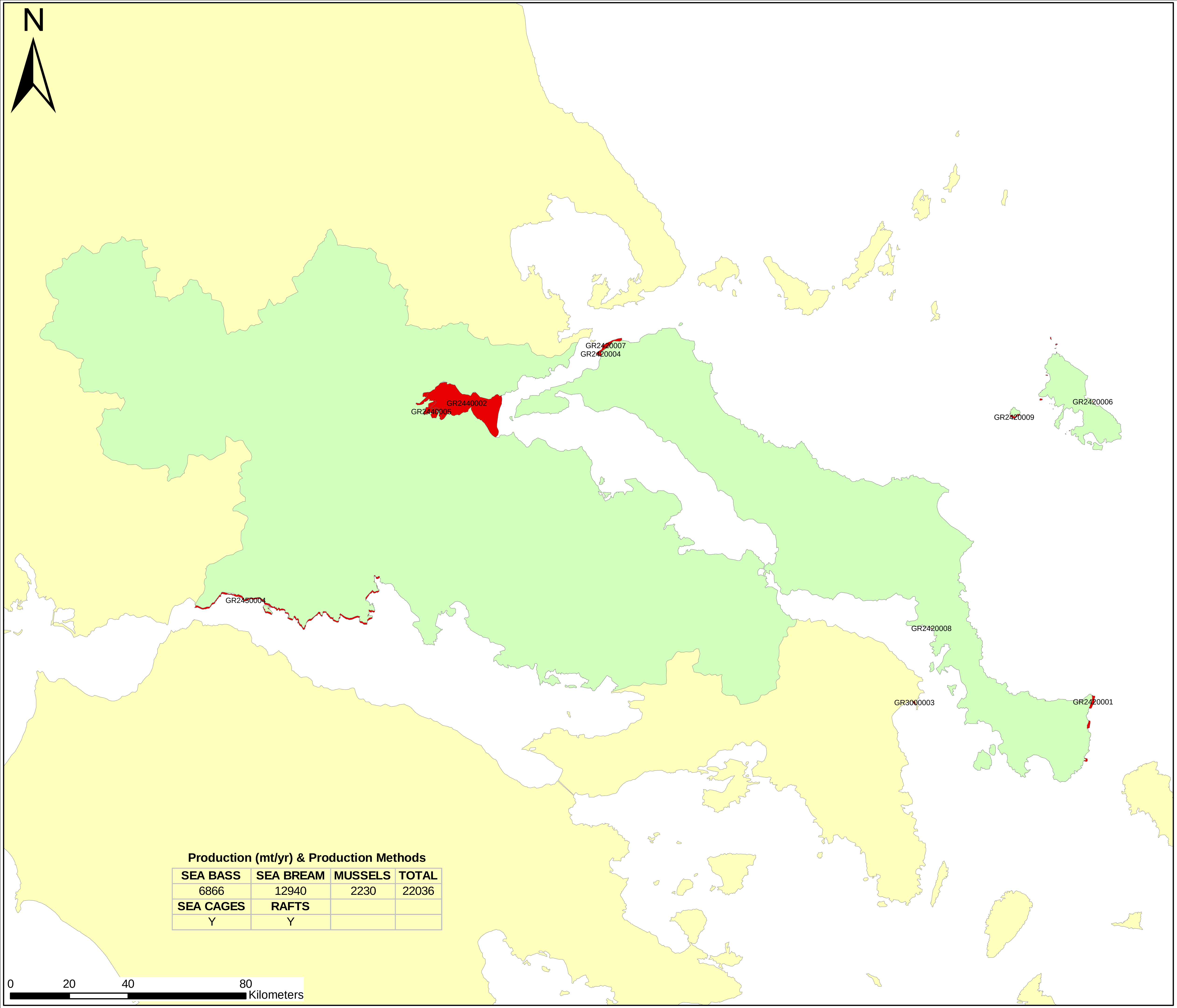
Title
South Western Scotland Conservation Areas

Scale	Drawn	Checked	Authorised
1:1,200,000 at A3	CG		
	Date 09/11/05	Date	Date

Drawing Number



Production (mt/yr) & Production Methods

SEA BASS	SEA BREAM	MUSSELS	TOTAL
6866	12940	2230	22036
SEA CAGES	**RAFTS**		
Y	Y		

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Legend

- N2K Regions
- Sterea Ellada
- Europe

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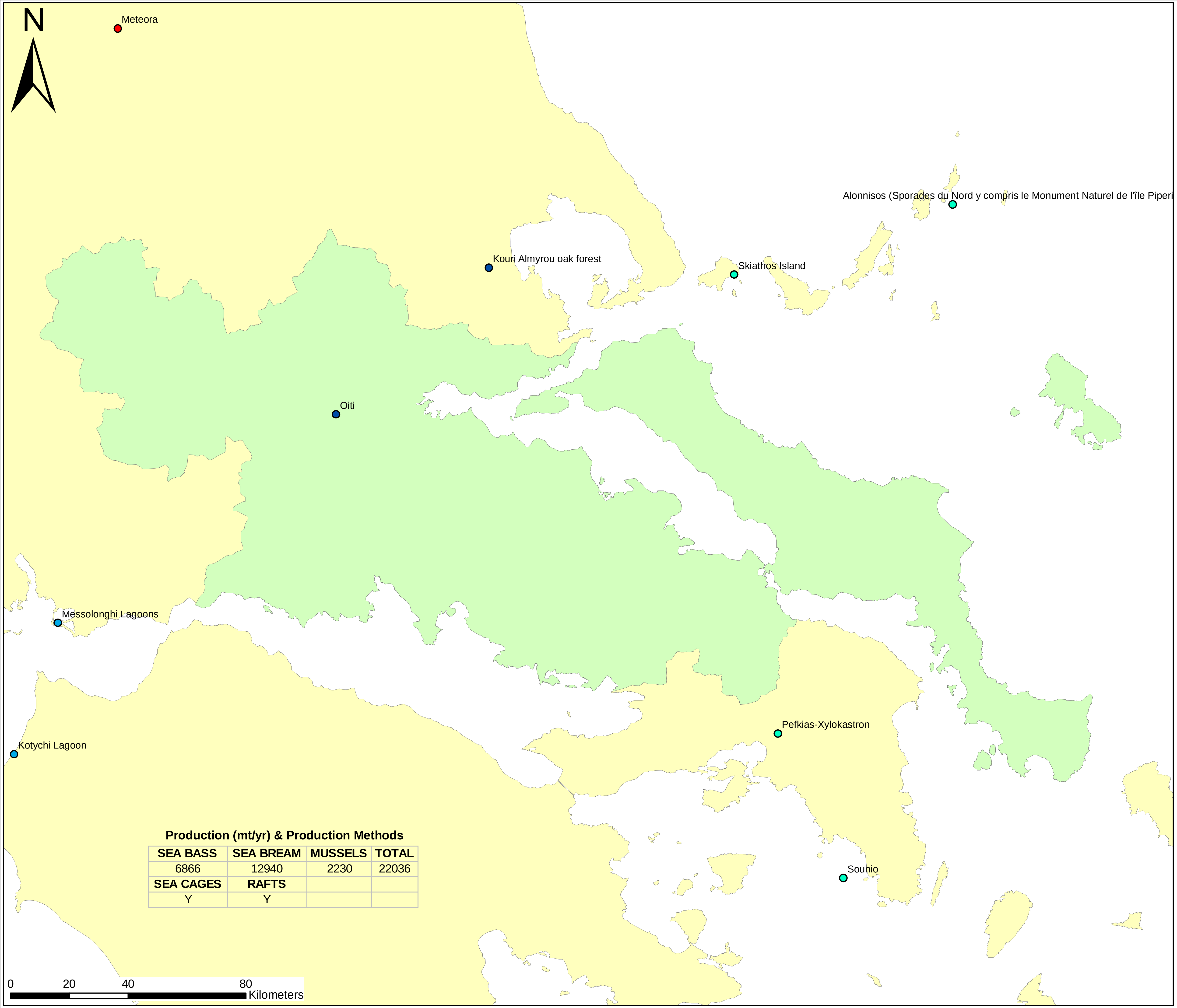
Title

Sterea Ellada N2K Regions

Scale	Drawn	Checked	Authorised
1:1,200,000 at A3	CG		
	Date 09/11/05	Date	Date

Drawing Number



Production (mt/yr) & Production Methods

SEA BASS	SEA BREAM	MUSSELS	TOTAL
6866	12940	2230	22036
SEA CAGES	**RAFTS**		
Y	Y		

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Legend

- Barcelona Convention SPA
- CoE Biogenetic Reserves
- CoE EuroDiploma
- Helsinki Convention
- Ramsar Sites
- Unesco BioSphere Reserves
- World Heritige Sites
- Sterea Ellada
- Europe

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Title

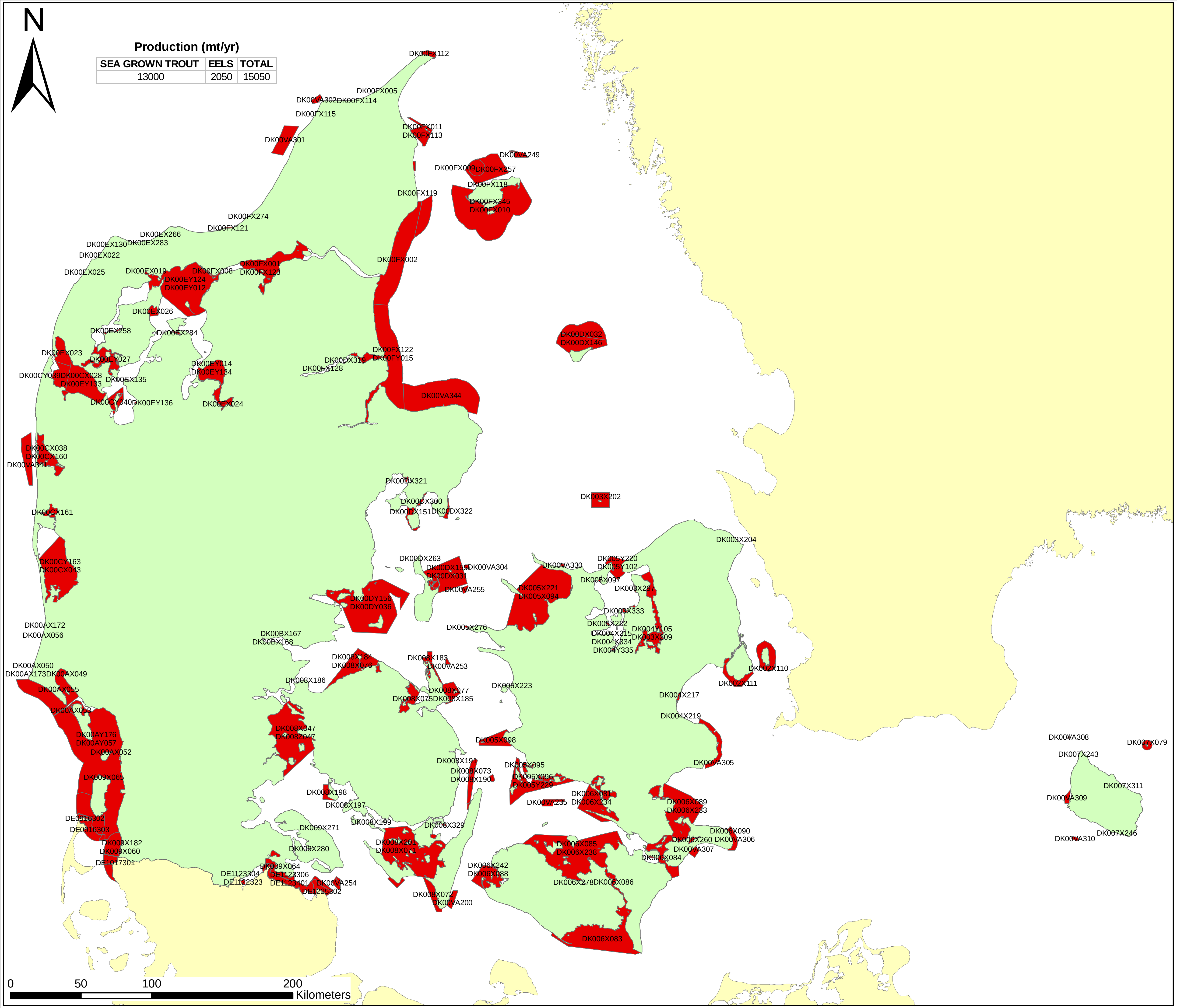
Sterea Ellada
Conservation Areas

Scale	Drawn	Checked	Authorised
1:1,200,000 at A3	CG		
	Date 09/11/05	Date	Date

Drawing Number

Production (mt/yr)

SEA GROWN TROUT	EELS	TOTAL
13000	2050	15050



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Legend

- N2K Regions
- Danmark
- Europe

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Description	By	Date	Authorised

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Title

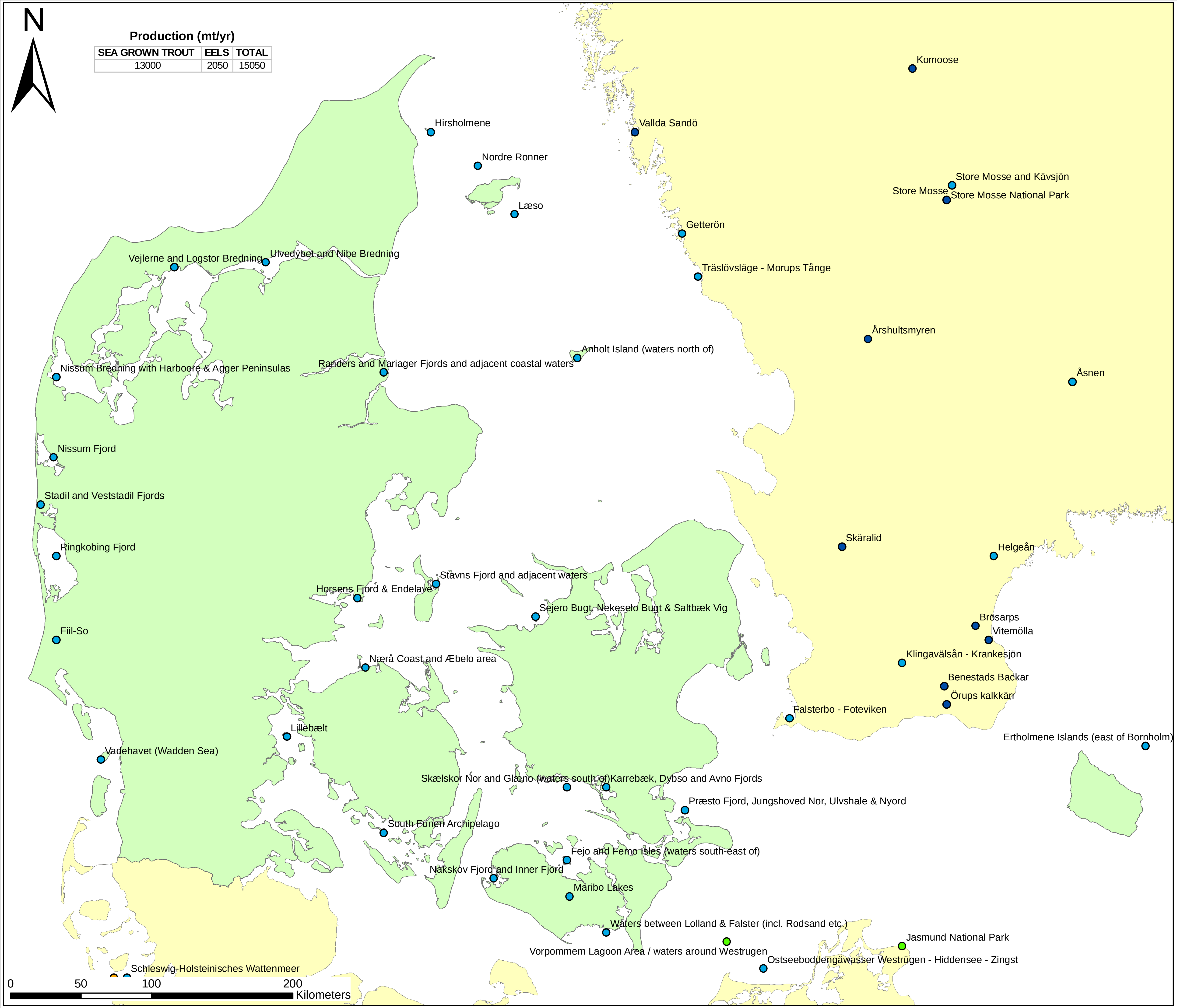
Danmark N2K Regions

Scale	Drawn	Checked	Authorised
1:2,500,000 at A3	CG		
	Date 09/11/05	Date	Date

Drawing Number

Production (mt/yr)

SEA GROWN TROUT	EELS	TOTAL
13000	2050	15050



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Legend

- Barcelona Convention SPA
- CoE Biogenetic Reserves
- CoE EuroDiploma
- Helsinki Convention
- Ramsar Sites
- Unesco BioSphere Reserves
- World Heritige Sites
- Danmark
- Europe

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Description	By	Date	Authorised

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Project

Title

Danmark Conservation Areas

Scale	Drawn	Checked	Authorised
1:2,500,000 at A3	CG		
	Date 09/11/05	Date	Date

Drawing Number

Appendix F: Spatial Representation of Shellfish Culture in the EU

A. European Wide Shellfish Production, 2003 (3 maps): These maps show the distribution of shellfish aquaculture around Europe. For each region, a pie chart indicates the quantity of shellfish being produced (in million tonnes per year) and also the proportion of shell fish type being farmed. Due to the absence of significant shellfish farming in the Northern European regions there are only three maps in this section.

B. Regional maps: top 4 shellfish-producing NUTS 2 regions:

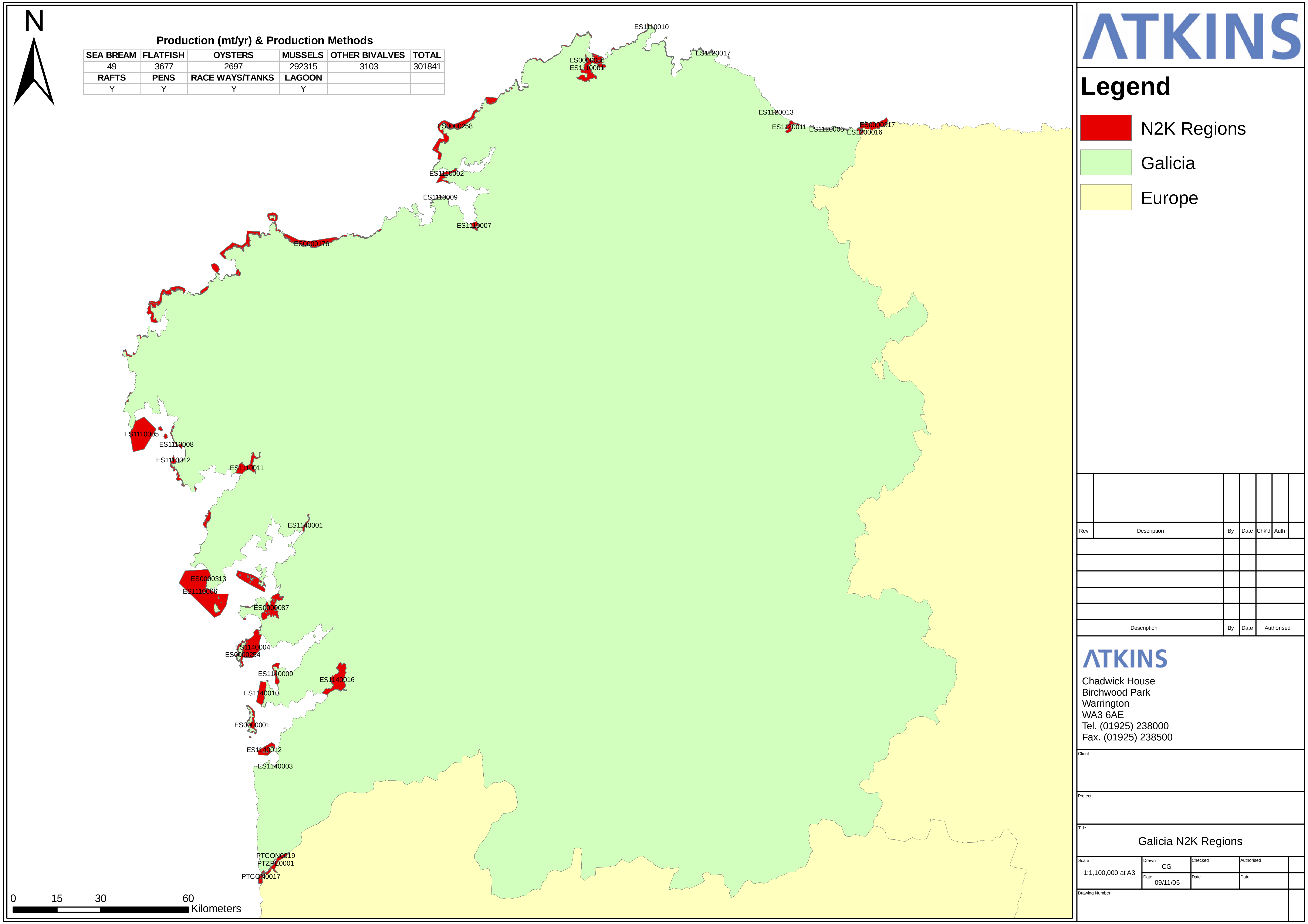
1. Galicia
2. West-Vlaanderen
3. Bretagne
4. Normandy

For each region two maps are produced showing (i) Natura 2000 areas and (ii) other conservation areas. For both map types, each designated area is labelled with either a unique reference number (for Natura 2000) or a site name (for other conservation designations.) In addition to the environmental information a table is displayed in each map detailing aquaculture production figures and techniques for that region.

Source: Spatial Applications Data, Leuven & project-derived production data

Production (mt/yr) & Production Methods

SEA BREAM	FLATFISH	OYSTERS	MUSSELS	OTHER BIVALVES	TOTAL
49	3677	2697	292315	3103	301841
RAFTS	PENS	RACE WAYS/TANKS	LAGOON		
Y	Y	Y	Y		



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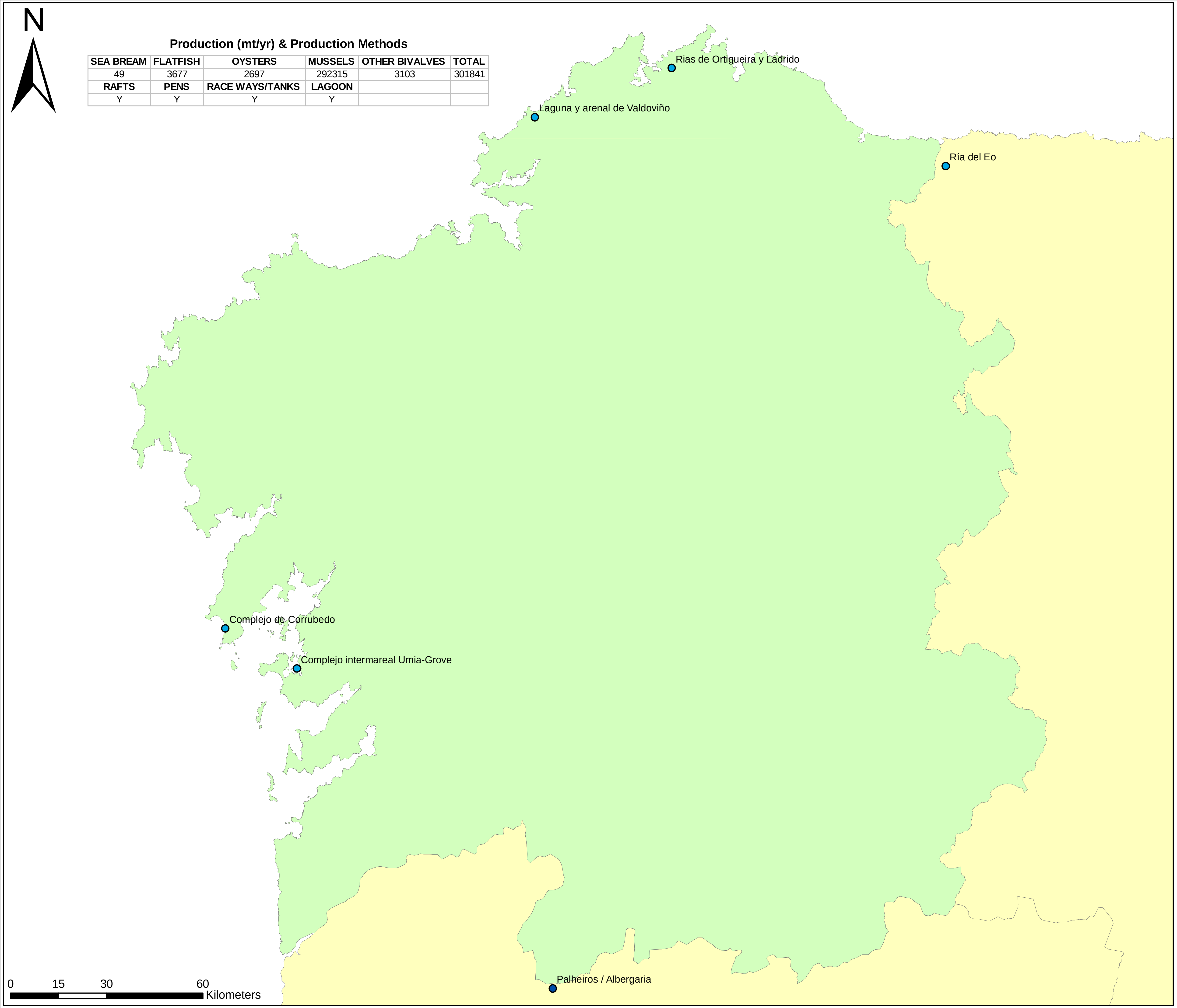
Title
Galicia N2K Regions

Scale	Drawn	Checked	Authorised
1:1,100,000 at A3	CG		
	Date 09/11/05	Date	Date

Drawing Number

Production (mt/yr) & Production Methods

SEA BREAM	FLATFISH	OYSTERS	MUSSELS	OTHER BIVALVES	TOTAL
49	3677	2697	292315	3103	301841
RAFTS	**PENS**	**RACE WAYS/TANKS**	**LAGOON**		
Y	Y	Y	Y		



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Legend

- Barcelona Convention SPA
- CoE Biogenetic Reserves
- CoE EuroDiploma
- Helsinki Convention
- Ramsar Sites
- Unesco BioSphere Reserves
- World Heritige Sites
- Galicia
- Europe

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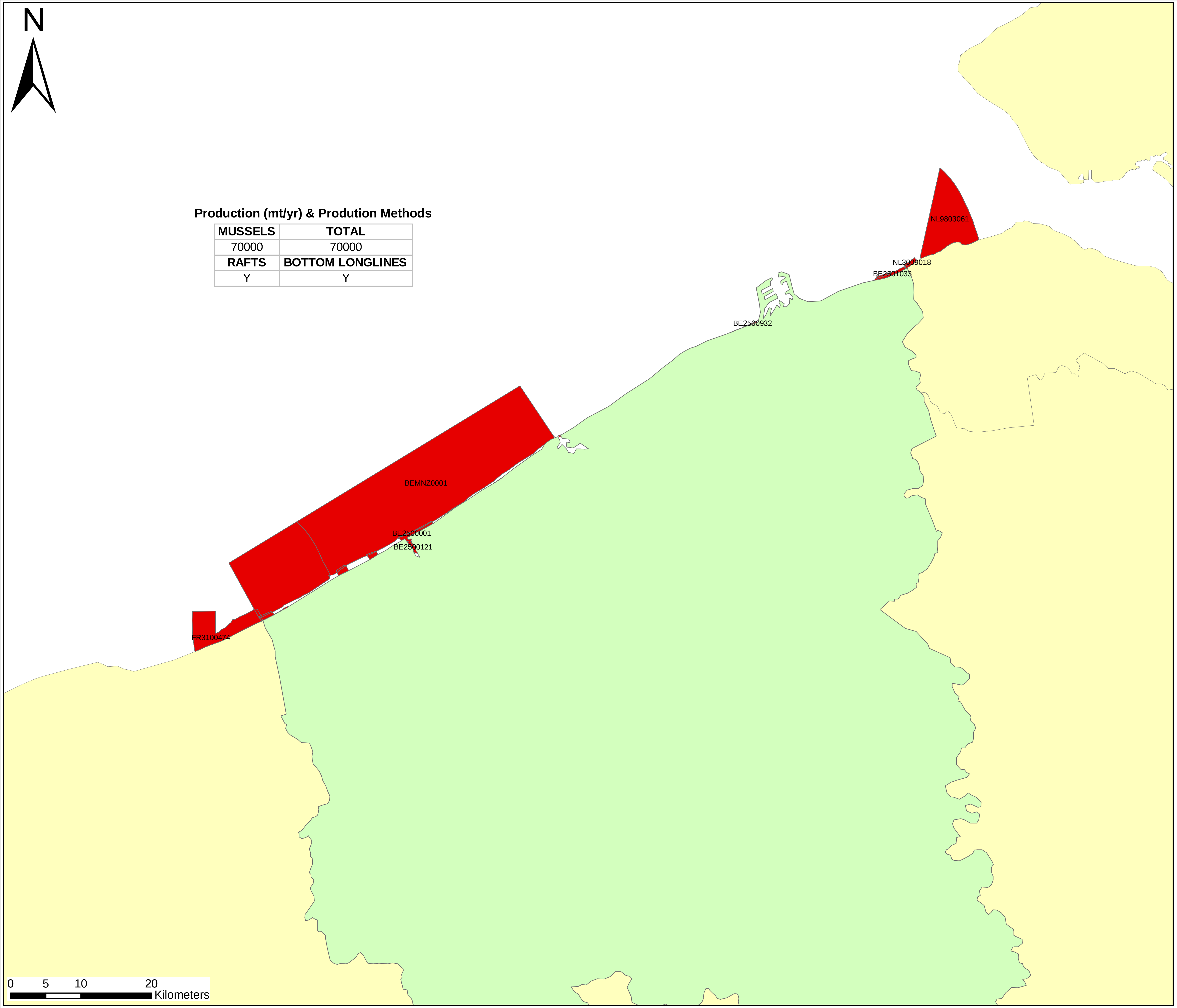
Title

Galicia Conservation Areas

Scale	Drawn	Checked	Authorised
1:1,100,000 at A3	CG		
	Date 09/11/05	Date	Date

Drawing Number



Production (mt/yr) & Prodution Methods

MUSSELS	TOTAL
70000	70000
RAFTS	**BOTTOM LONGLINES**
Y	Y

ATKINS

Legend

- N2K Regions
- West Vlaanderen
- Europe

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Description	By	Date	Authorised

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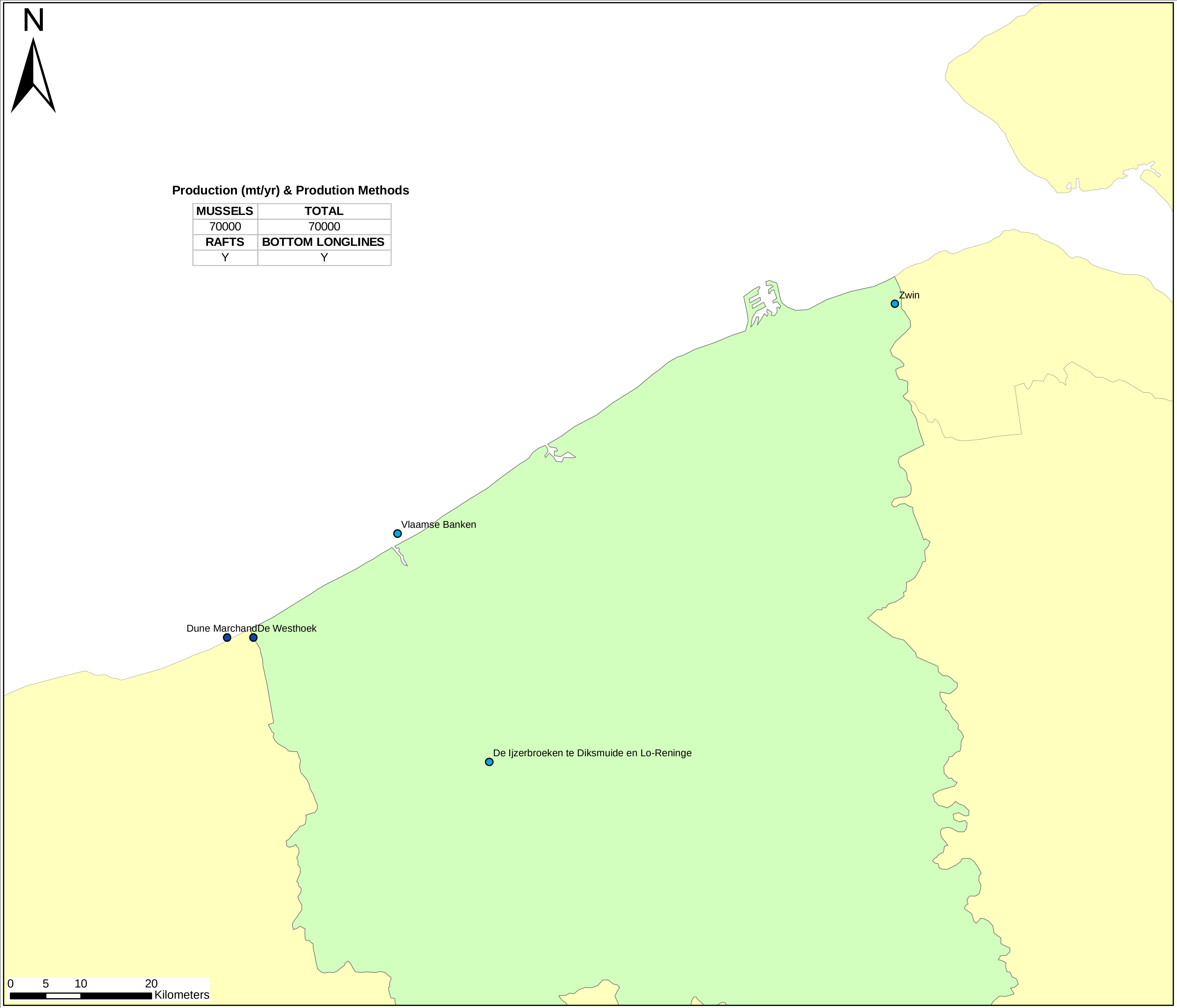
Title

West Vlaanderen N2K Regions

Scale	Drawn	Checked	Authorised
1:500,000 at A3	CG		
	Date 09/11/05	Date	Date

Drawing Number



Production (mt/yr) & Prodution Methods

MUSSELS	TOTAL
70000	70000
RAFTS	**BOTTOM LONGLINES**
Y	Y

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Legend

- Barcelona Convention SPA
- CoE Biogenetic Reserves
- CoE EuroDiploma
- Helsinki Convention
- Ramsar Sites
- Unesco BioSphere Reserves
- World Heritige Sites
- West Vlaanderen
- Europe

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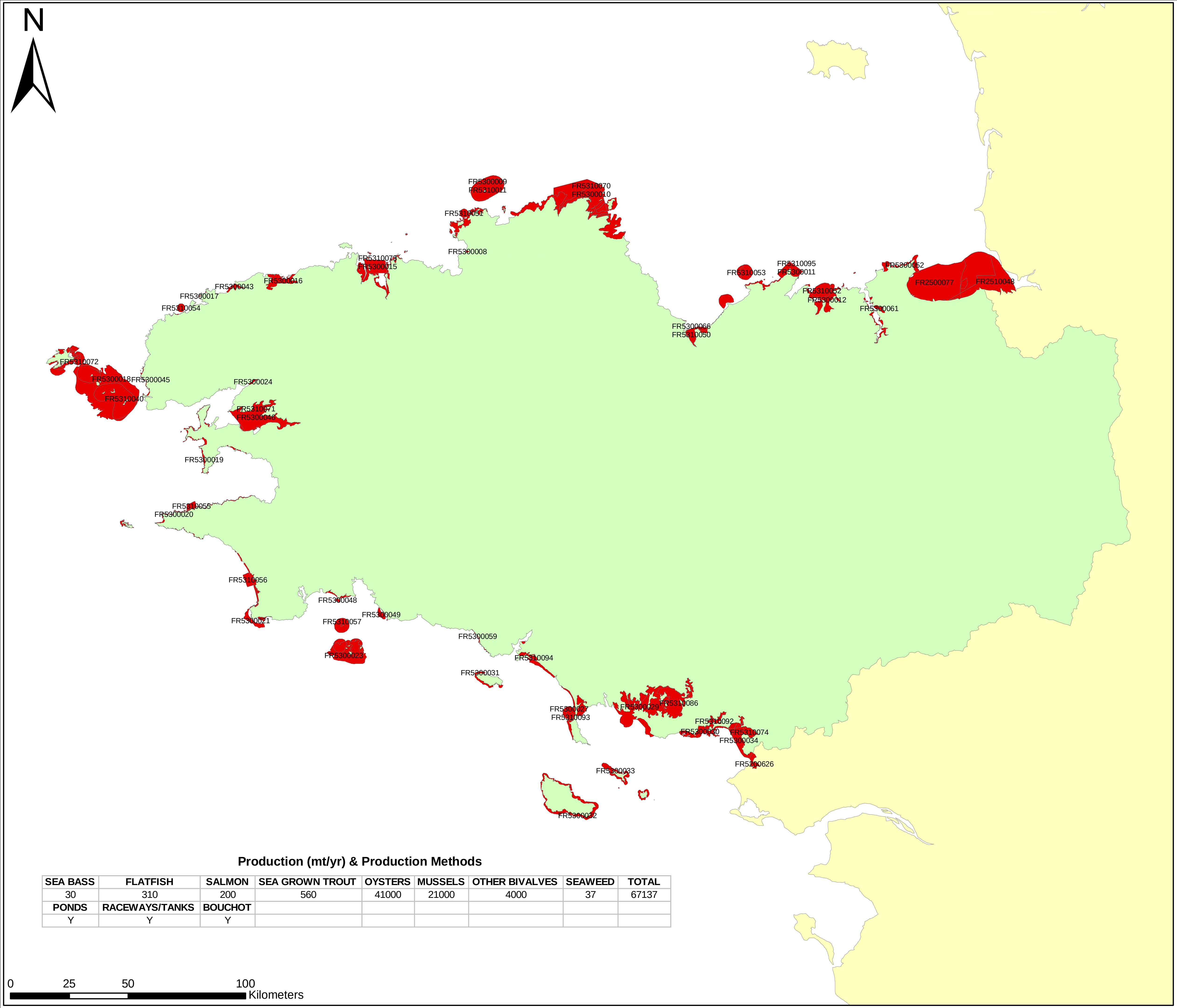
Title
West Vlaanderen
Conservation Areas

Scale	Drawn	Checked	Authorised
1:500,000 at A3	CG		
	Date 09/11/05	Date	Date

Drawing Number



Production (mt/yr) & Production Methods

SEA BASS	FLATFISH	SALMON	SEA GROWN TROUT	OYSTERS	MUSSELS	OTHER BIVALVES	SEAWEED	TOTAL
30	310	200	560	41000	21000	4000	37	67137
PONDS	RACEWAYS/TANKS	BOUCHOT						
Y	Y	Y						

ATKINS

Legend

- N2K Regions
- Bretagne
- Europe

Rev	Description	By	Date	Chk'd	Auth

Description	By	Date	Authorised

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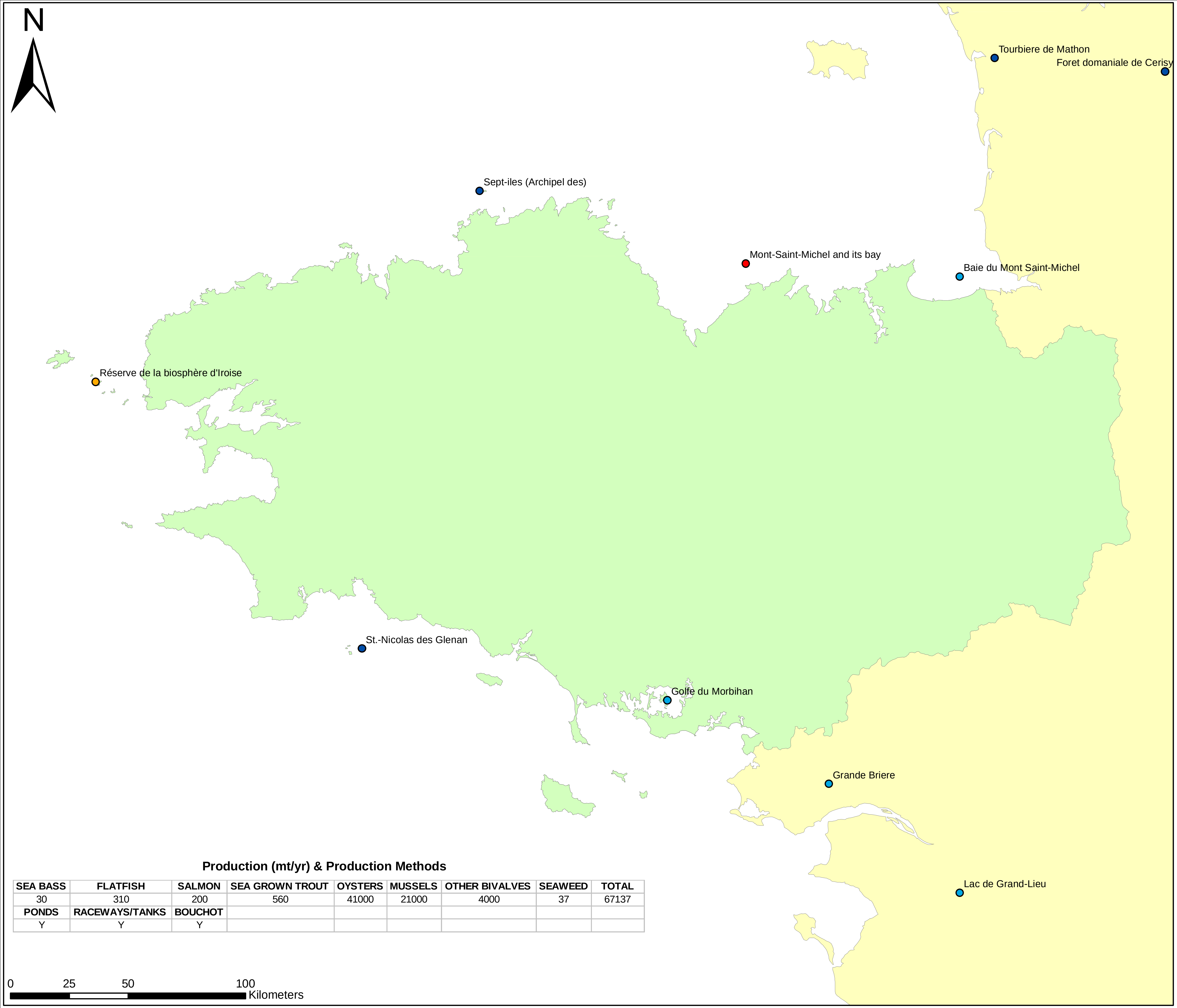
Title

Bretagne N2K Regions

Scale	Drawn	Checked	Authorised
1:1,500,000 at A3	CG		
	Date 09/11/05	Date	Date

Drawing Number



Production (mt/yr) & Production Methods

SEA BASS	FLATFISH	SALMON	SEA GROWN TROUT	OYSTERS	MUSSELS	OTHER BIVALVES	SEAWEED	TOTAL
30	310	200	560	41000	21000	4000	37	67137
PONDS	**RACEWAYS/TANKS**	**BOUCHOT**						
Y	Y	Y						

ATKINS

Legend

- Barcelona Convention SPA
- CoE Biogenetic Reserves
- CoE EuroDiploma
- Helsinki Convention
- Ramsar Sites
- Unesco BioSphere Reserves
- World Heritige Sites
- Bretagne
- Europe

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Description	By	Date	Authorised

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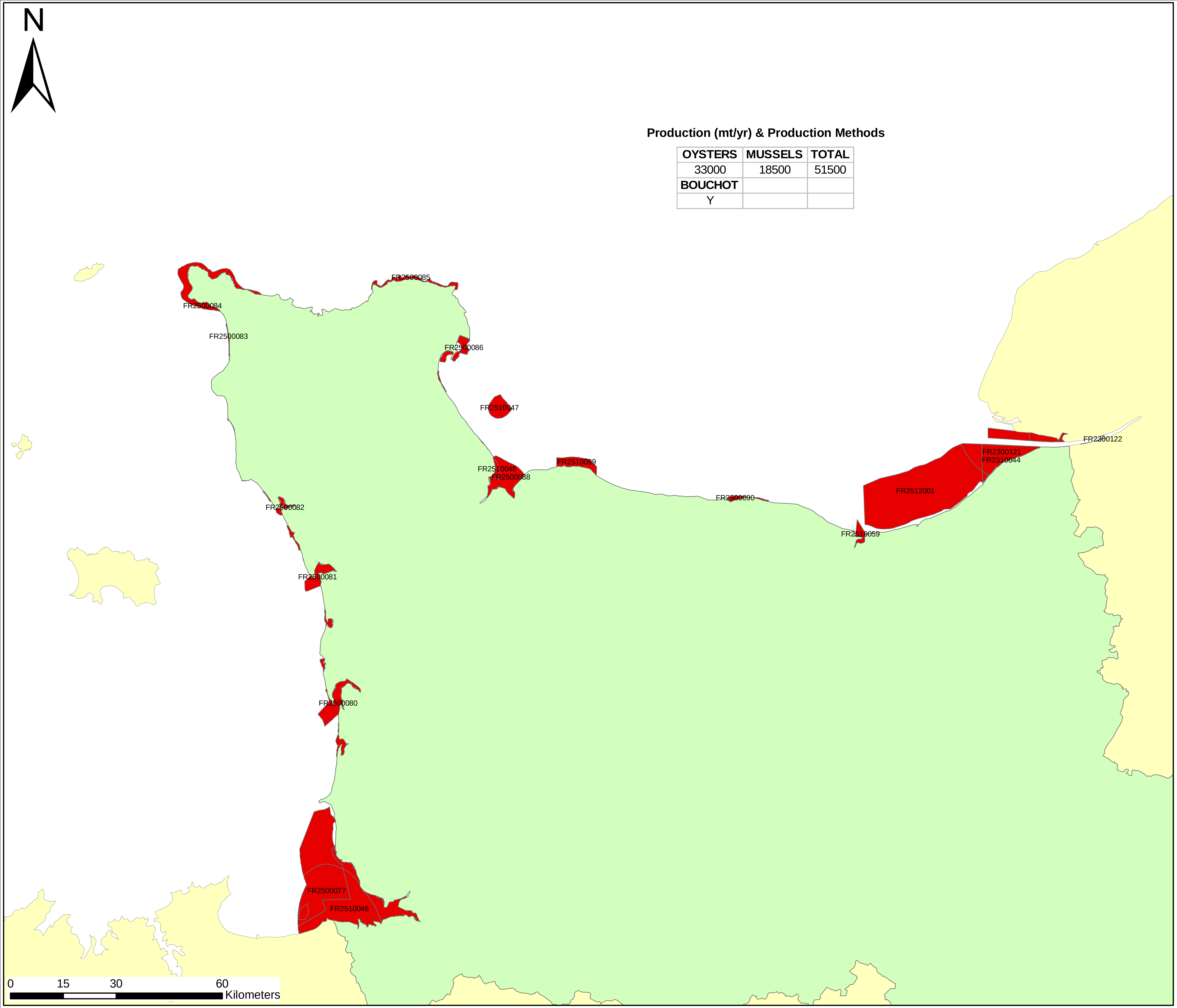
Title

Bretagne Conservation Areas

Scale	Drawn	Checked	Authorised
1:1,500,000 at A3	CG		
	Date 09/11/05	Date	Date

Drawing Number



Production (mt/yr) & Production Methods

OYSTERS	MUSSELS	TOTAL
33000	18500	51500
BOUCHOT		
Y		

ATKINS

Legend

- N2K Regions
- Normandie
- Europe

Rev	Description	By	Date	Chk'd	Auth

Description	By	Date	Authorised

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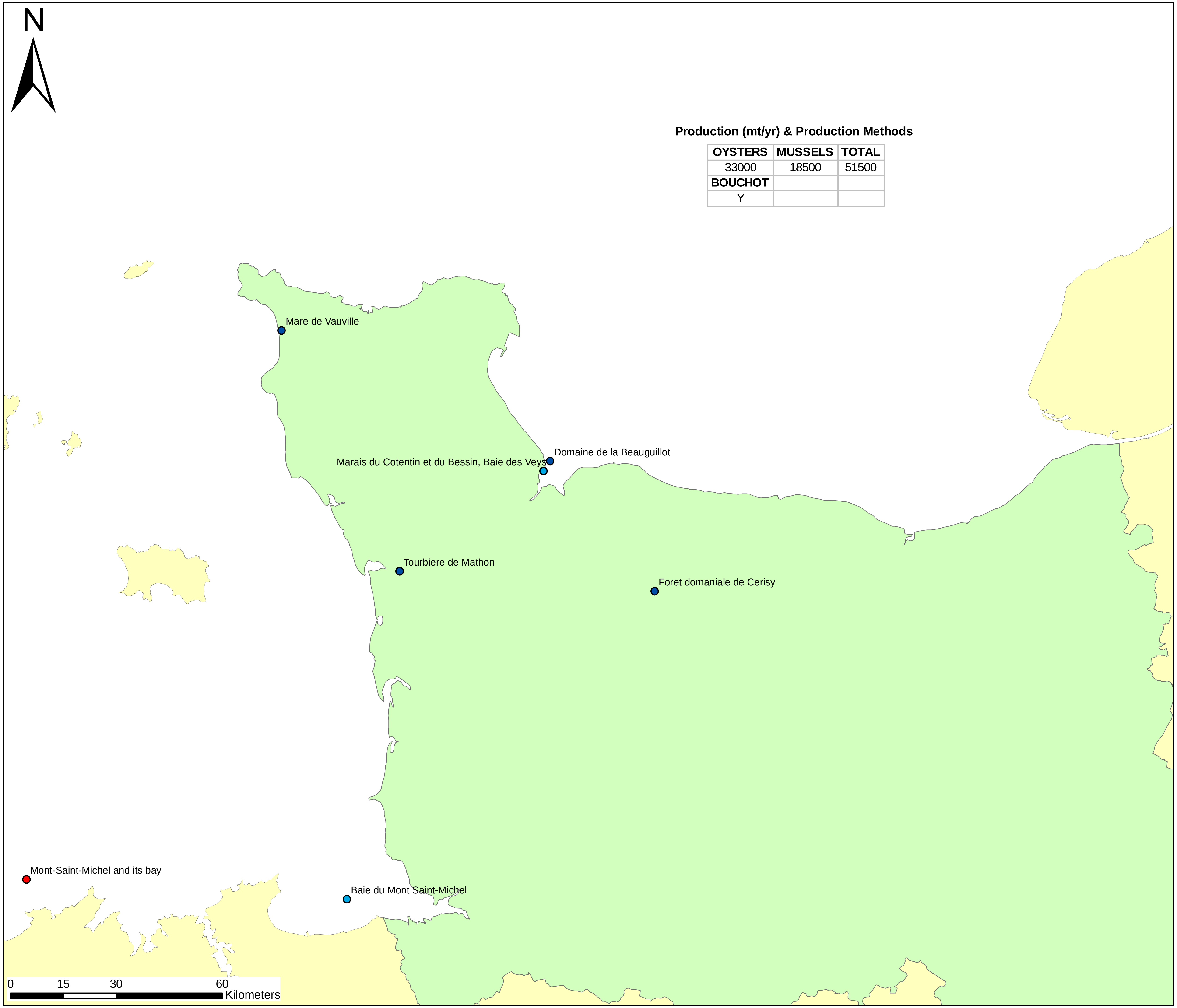
Project

Title
Normandie N2K Regions

Scale	Drawn	Checked	Authorised
1:1,000,000 at A3	CG		
	Date 09/11/05	Date	Date

Drawing Number



Production (mt/yr) & Production Methods

OYSTERS	MUSSELS	TOTAL
33000	18500	51500
BOUCHOT		
Y		

ATKINS

Legend

- Barcelona Convention SPA
- CoE Biogenetic Reserves
- CoE EuroDiploma
- Helsinki Convention
- Ramsar Sites
- Unesco BioSphere Reserves
- World Heritige Sites
- Europe
- Normandie

Rev	Description	By	Date	Chk'd	Auth

Description	By	Date	Authorised

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Warrington
WA3 6AE
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Client

Project

Title

Normandie Conservation Areas

Scale	Drawn	Checked	Authorised
1:1,000,000 at A3	CG		
	Date 09/11/05	Date	Date

Drawing Number