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Report of the Working Group on Marine Shellfish Culture (WGMASC)

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Contents

Executive summary

The 5th meeting of the Working Group on Marine Shellfish Culture (Chair: Peter J. Cranford, Canada) was held Halifax (Canada) and was attended by 11 participants.

ToR a) This ToR deals with the issue of unexplained mortality in shellfish and the 2007 objective was to produce a diagnostic tool that the shellfish aquaculture sector could use as a model to monitor and deal with mortality issues. An operational flowchart and set of working tables were developed to assess the types of mortality that a shellfish grower might encounter in the field and what may have caused these losses. These were designed to be practical in nature and to be used by farmers and resource managers. Simple measurements were recommended although more complex approaches may be warranted. A monitoring system was also recommended to allow for early detection of problems and to provide a point of reference for future changes in shellfish production. Additional steps need to be taken to make the diagnostic tool functional for aiding in the identification of causes of mortality in cultured shellfish. First, the tables need to be peer reviewed and shellfish industry input is required. Second, the diagnostic tool should be published and distributed to the farmers (e.g. through producer organisations) and local managers in the languages of ICES countries. We recommend that an ICES Cooperative Research Report be prepared on this topic with science peer review by relevant working groups under the direction of the MCC (Section 3; linkages to MCC, ACME, WGPDNO, WGEIM).

ToR b) There are many components and tools that need to be evaluated and integrated into an ecosystem management framework for shellfish aquaculture. This report reviews concepts and desirable features of environmental indictors, existing indicator frameworks, classes of indicators and selection criteria. A preliminary list of benthic and pelagic indicators specific to shellfish culture is provided along with a discussion of operational management thresholds. Environmental conservation and protection legislations in place within ICES countries are important considerations for the selection of ecological status/performance indicators, and particularly for the setting of management triggers/thresholds. These are reviewed in the context of Integrated Coastal Zone Management (ICZM) activities in many ICES countries. The ICZM policy framework can be used as a vehicle to recognise, address, and minimise conflicts pertaining to aquaculture operations in a timely fashion. Social and economic properties and legislative and policy frameworks determine the type and the intensity of aquaculture activities and relevant economic and social parameters therefore need to be identified and included as indicators for shellfish aquaculture. ICZM can been seen as tool to overcome the conflict prone situation in aquaculture activities, as one of its key principles is to view problems in a wide context. (Section 4; linkages to MCC, ACME, WGPDNO, WGEIM, WGICZM)

ToR c) There are problems managing wild stocks of molluscs world wide such that innovative management methods are currently being developed and employed in tandem with existing legislative measures to address these issues (e.g. scallop, oyster and mussel species). The operation and rotation of closed areas and the utilisation of ranching techniques are being successfully combined with aquaculture techniques to augment recruitment and to rejuvenate wild stocks. There is evidence for stabilisation/maintenance of recruitment and yields and increases in biomass in certain fisheries. The benefits of integrating aquaculture methodology with wild fisheries can result in sustained increases in production of harvestable animals. There is currently little coordinated policy amongst ICES countries to maximise the potential of integrated aquaculture and fisheries. Current experience has shown (1) the need for rotation of multiple closed areas rather than individual areas, and (2) that fishermen must play a key role to ensure success. (Section 5; linkages to MCC, ACME, WGEIM)

ToR d) Emerging shellfish aquaculture issues identified, in order of decreasing priority, are; (1) aquaculture transfers between sites/countries, (2) climate change effects on shellfish aquaculture distribution and production, (3) benefits and pitfalls of new aquaculture technologies, and (4) alternative and value-added uses of cultured shellfish resulting in increased production levels, value and benefits in distribution. (Section 6; linkages to MCC, ACME, WGEIM, WGPDNO, BEWG, WGBOSV, WGITMO, WGBEC, WGAGFM)

1 Opening of the meeting

The ICES Working Group on Marine Shellfish Culture [WGMASC], chaired and hosted by Peter Cranford (Canada), held its fifth meeting in Halifax (Canada) on 27–29 May 2007 at the Bedford Institute of Oceanography (BIO).

The meeting was opened at 9:30 on Tuesday 27 May, with Tom Sephton (Head, Ecosystem Research Division, Fisheries and Oceans Canada) welcoming the group to BIO. Dr. Sephton, past chair and current member of the Mariculture Committee (ICES MCC), provided a general overview of current ICES activities (e.g. restructuring planning) and the role of the WGMASC within the evolving ICES framework. Peter Cranford welcomed the members to the meeting and introduced the newest member (Øivind Strand, Norway) and the three appointed members. In response to the relatively small size of the WGMASC, the chair appointed three members for a one year period. Dr. Edward Black (Ottawa, Canada) was invited to provide expertise and continuity of advice on relevant activities in the WGEIM and in GESAMP. Dr. Adoracion Sanchez Mata (Xunta de Galicia, Spain) accepted the chair's invitation to provide input on EU projects and particularly with Project MARAQUA on the monitoring and regulation of marine aquaculture in European countries. Dr. Gesche Krause (Bremen, Germany) was invited to provide expertise on all National Integrated Coastal Zone Management strategies of the member states of the European Union, which were evaluated in 2006. Each member of the WGMASC provided a brief overview of their relevant research activities and expertise.

The chair presented an overview of the WGMASC 2006 report to the MCC and resulting recommendations. Highlighted was the (1) the postponement of the joint WGEIM and WGMASC theme session on "Ecological Carrying Capacity in Shellfish Culture" to the ASC 2008 in Halifax, and (2) the potential genetic significance of using hatchery-reared scallops to enhance wild stocks, which requires further development within the WGMASC and interaction with the WGAGFM.

The WGMASC Terms of Reference (Annex 2) were reviewed. Three of four ToR's are ongoing, with a new ToR (d) added for 2007 based on a 2006 recommendation from the WGMASC. The opening plenary session contained a general discussion of the four ToR's and it was suggested that the group should be able to complete ToR's a and c during the 2007 meeting. ToR b will remain ongoing for several years to be able to address the many linked activities that make up a framework for the integrated evaluation and management of the impacts of shellfish aquaculture in the coastal zone. The opening plenary session ended with a discussion of the new ToR d, and several preliminary emerging issues were flagged for inclusion in the response by the WGMASC.

2 Adoption of the agenda

A general discussion was held on how the WGMASC should organize the work under each of the Terms of Reference. The WGMASC decided to continue the past practice of addressing each ToR separately within subgroups, followed by plenary sessions where subgroup activities are discussed by the full WGMASC and the draft report is formally accepted. ToRs a, b and c were addressed simultaneously by subgroups, while ToR d was discussed in each of the plenary sessions. The agenda (Annex 2) was modified slightly to accommodate the discussed work plan and was formally accepted with the inclusion of brief presentations on March 28, 2007 by Drs. Edward Black and Gesche Krause during plenary.

Subgroup leaders appointed by the WGMASC chair were Shawn Robinson (ToR a), Edward Black (ToR b) and David Fraser (ToR c). Each subgroup leader acted as rapporteur for preparing draft reports from the work of subgroups and reported on the group activities during plenary sessions.

3 Prepare a state of knowledge report comparing and contrasting the standard methods used to measure stress indicators in shellfish and provide a discussion of how they would be used to diagnose incidents of cultured shellfish mortality (ToR a)

3.1 Background

The objective of this ongoing term of reference is to determine how stress indicators can be employed to predict and assess a problem and be used in conjunction with known environmental, biological and chemical variables to diagnose the cause of cultured shellfish mortality.

It is well documented that stress indicators measure a deviation from a normal state of health; they may be intrinsic or extrinsic, supplying contextual and/or specific information. Each test index, whether supplying general observations or sensitive, specific diagnostic information, can be developed to grade the presence and severity of a single or multiple effects. These graduations of effect can then be used to determining the severity of a problem, indeed deciding whether the measured effect is a real problem or simply identifying the presence of an agent with the potential to cause a problem, including mortality. Ideally, such tests should be relatively easy, quick and specific and capable for use by non-technical farm site personnel, although it must be recognized that more complicated diagnoses may be required.

3.2 Introduction

The WGMASC 2004 report identified a series of biochemical and physiological measurements that were reflective of a suite of stressors on cultured shellfish. Such stressors ranged from environmental variables (e.g. temperature, salinity, food availability) to biological (such as pathogens) to chemical (e.g. contaminants). The tests outlined would almost exclusively have to be executed in specialised laboratory situations and consequently would be regarded as resource and time consuming.

The WGMASC 2005 report listed a series of more general observations relating to the diagnosis of stress in shellfish populations. In addition, the group acknowledged that in order to determine the cause of a problem in cultured shellfish populations, an investigation could be carried on the organism in question to determine the response to varying degrees of stress. However, such information pertaining to biological effects of individual stressors is often not known. Prior to the application of a series of sophisticated tests, a number of preliminary and fundamental observations could form the first phase of a diagnostic process (see below). The answers to some basic questions may serve a number of functions. Primarily they could be used to carry out a preliminary diagnosis, with the goal of identifying a list of potential stressors. This might be achieved by identifying the observed response in the cultured shellfish and relating this to previously documented stressor responses. If individual stressors were not identified clearly by this first phase of diagnosis, this background information could inform (guide) subsequent (and likely costly) laboratory based diagnostic testing. This background or supporting information may be generated by a number of means; the most useful is likely to come from the farmer themselves who should be encouraged to observe and record as much information as possible on the culture stock as well as some basic environmental parameters in the vicinity of the culture area. These diagnostic questions relate specifically to the extent (spatial and temporal) of the problem and how it manifests itself in the organisms in question (measurement in WGMASC (2004) or observations of variable in WGMASC (2005)). In addition, it broadens the sphere of investigation to assess wider environmental factors and considers temporal and spatial factors as well (i.e. ecosystem approach).

It is acknowledged that abnormal mortalities in wild fisheries and in shellfish culture facilities within European member states must be reported under European Union Directives, 91/67/EC and 95/70/EC and the newer version of 91/67/EC, which will combine both pieces of legislation. Typically if above average mortality (not clearly defined) is observed, the shellfish farmer is obliged to report the mortality and provide samples of shellfish for disease analysis (standard suite of analysis). Consequently, specific diseases and HABs are excluded from this review as many are covered by conventional monitoring programmes governed by legislation that covers human health and/or fish health issues. For information purposes, a list of potential shellfish diseases relevant and applied for diagnostic techniques is provided in ANNEX 5. The information generated by the process outlined below can be gathered in parallel with statutory disease analysis and any other management actions the regulatory agencies deem necessary (e.g. closure of culture area and restricted movement of shellfish). Ultimately, a case history can be developed of the circumstances leading to the mortality event and this will subsequently provide the context within which conclusions can be drawn regarding the causative agent(s) and any action to be taken, for example control and/or eradication of disease. A similar exercise has been conducted by IFREMER whereby the potential causative agents for the summer mortality syndrome in *Crassostrea gigas* were examined and reviewed recently

(http://www.ifremer.fr/morest-gigas/index.htm;
http://www.ifremer.fr/lern/Pages/Programme/morest.htm).

3.3 Framework

The development of a framework to determine and handle causes of shellfish mortality is really a component of a larger system to handle biosecurity of a shellfish farm and the surrounding growing region. It should be built around three pillars: 1) the introduction of measures to minimise the risk of introducing a potential problem 2) a monitoring plan to provide an early warning system for problems and to generate baseline information to determine norms and trends and 3) a diagnosis and solution portion to have a consistent response in dealing with these mortalities. The combination of these techniques will play an important role in the biosecurity of the shellfish farming region. Risk assessments can play an important part in minimising the risk of the introduction and spread of disease or an environmental impact, via the introduction of preventative measures based on results of those assessments.

The monitoring plan should ideally incorporate both farm-based observations as well as those from external monitoring programs by other groups or agencies. Farm-based observations would include a suite of standardized observations that may be species specific and that were of direct use to the farmer (e.g. meat yields). They could include information on morphometrics, calculated ratios (e.g. condition factors), associated species (type and relative abundance), behaviours, and physical measurements (e.g. temperature, salinity, nutrients, secchi depth). These data would be held in a common database and regular summary reports would be generated. In addition to the farm-based monitoring plan, links should be made with external monitoring programs in order to provide some synergy. Some of these outside programs may include: disease surveys, hydrographic surveys, mussel watch programs, harmful algal bloom programs, fishery surveys etc. The ultimate goals of the monitoring program would be to 1) determine the baseline information for several parameters of relevance to the shellfish industry and detect any trends over time and 2) to provide an early warning system to the growers of changing conditions, based on historic experience, that the growers can use with adaptive management techniques. The monitoring section is integral to the portion dealing with the mortality events as it will give a point of reference.

The diagnosis and resolution plan uses a flowchart-type system to deal with the mortality issues. While the direct mortality event affects the grower initially, there are actually effects throughout the system and therefore resource managers and sometimes science will become involved. Once a problem is detected, a report is generated to the appropriate parties. This would include the farmer and various regulatory authorities (federal, provincial, state, industry associations). At this point a decision is made whether more samples are required (if yes, then more are collected). Once the appropriate samples are in place, a diagnosis of the problem is made. This may be a simple diagnosis by the farmer in which case he can go on to resolve the issue and then continue monitoring. If the diagnosis is not so simple, then science may be brought in to look at the problem with more sophisticated techniques of resolution, such as those shown in Table 1. A schematic of the protocols to deal with farm-site monitoring, diagnosis and resolution is shown in Fig. 1.

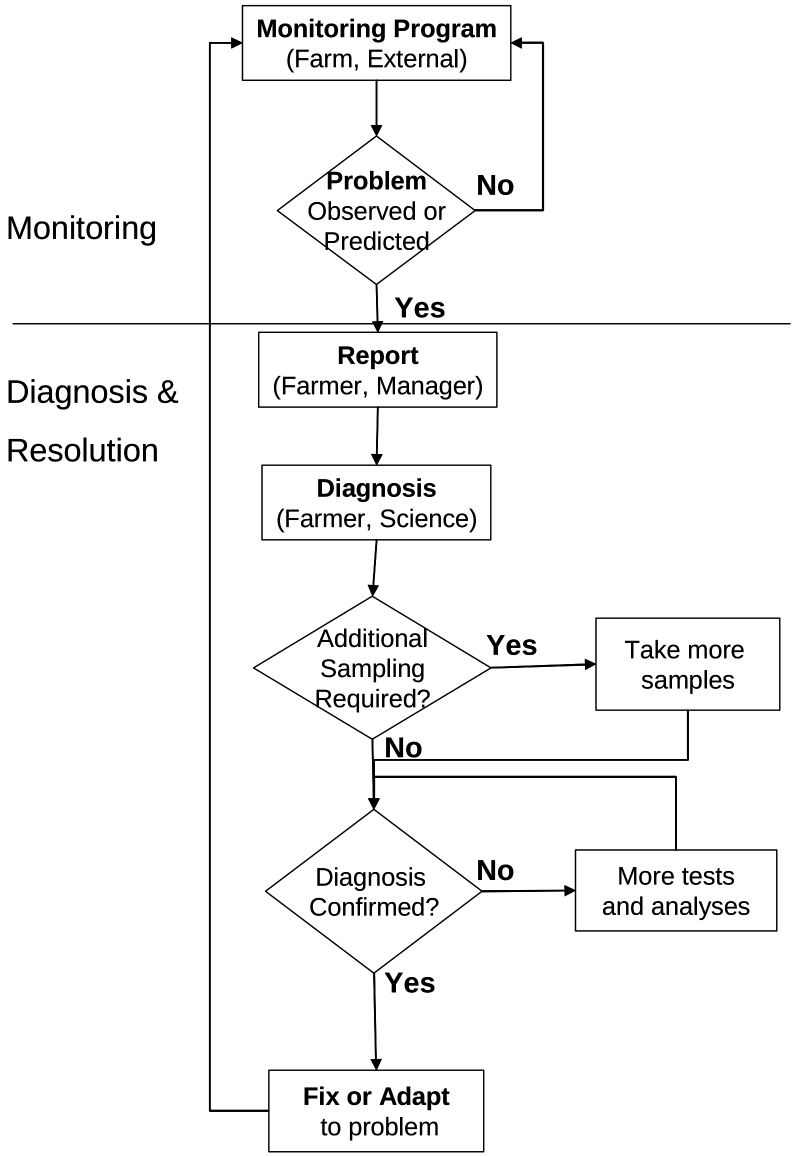

Figure 1. Schematic diagram of the pathway of implementation of the diagnostic protocol to deal with shellfish mortality for the running of a commercial shellfish farm.

3.4 Target audience

The target audience of this protocol will range from the shellfish farmer to the resource manager to supporting scientist. On the front line is the shellfish farmer who is confronted with an unexplained mortality event, wants to know the cause and has the ability to contribute case details on the culture process and the growth environment. This information will provide the basis of a case history in the event of a serious mortality event or problem. In addition, the proximity of the client to the culture environment will allow for the measurement of environmental conditions in a timely fashion. The shellfish farmer will likely be capable of undertaking the practical observations recommended and to quantify the results from a sample representative of a population. As more sophisticated information is required, specialized laboratories can become involved to process those samples and produce the synthesized data. The purpose of this document is to describe the phases of a diagnostic process within which a body of information can be generated in order to identify the causes of stress in cultured shellfish and perhaps, to help inform the use and development of more sophisticated tools (e.g. histopathology, biochemical/physiological screening).

The scales of responsibility for monitoring can be split among the various interest groups. Farmers are best suited to monitoring conditions on their own farm, however as the spatial scale increases, other organizations may need to become involved. For larger businesses or organized industries, company veterinarians or shellfish associations could become involved in monitoring from the farm-scale to bay-scale. For scales that encompass the entire industry in a country, state or province, the regulatory agencies should be involved from the farm-scale to the industry-scale.

3.5 Risk of mortality, warning signs

To monitor, test and predict for a problem, a rank of tests could be employed, e.g. observation, followed by a practical, chemical or molecular test, listing tests by risk analysis, thus identifying priorities. This could include stress testing, by exposing animals to conditions which may invoke a response, e.g. survival in air, or ability to burrow in clams or measure strength of muscle closure in scallops.

These tests may be applied in relation to knowledge of differing environmental conditions, by calibrating conditions to the point of death.

3.6 Stress Indicators

An attempt has been made to identify traits or parameters which describe sub optimal conditions, simple characteristics, observable and by test, prior to deleterious effect (Tables 1 and 2.)

Reference has been made to the 2005 WGPDMO which considers health indices. The presence or absence of a problem may be revealed by a stress indicator, by observation, monitoring, testing and analysis. Moving from general to specific diagnosis via screening to confirmation may lead to a single or multiple causative agents. It is therefore important to observe certain parameters such as behaviour and physiological condition, empirically measure physiological and test chemical function, and susceptibility to death via challenge. An estimation of mortality levels within a population should also be considered.

An indicator should allow simple fast measurements, analysis of complex processes and test results. These analyses should be useable by and explainable to non specialists, such that they can take action to prevent and limit effect. Early warning of a problem is essential, e.g. applying a fast specific and sensitive test for known parameters. They should be systematic, robust management tools, communicating changes which have the potential to lead to a problem and direct to appropriate action. They may take the form of ranked protocol of practical, chemical and molecular tests, which authorities and industry could take responsibility for developing and promoting their use.

Table 1 lists appropriate observations, a practical test of their impact and their influence on a population, in an attempt to diagnose a potential problem. Note that this is a general guide to stress indication, where one or more parameters may influence a diagnosis. Physiological condition of animals, such as maturity success, although not stress indicators in themselves, can influence recognition of a problem.

Table 1. Diagnosis of stress by observation, test, and influence on a population

OBSERVATIONS OF VARIABLE	TEST A REPRESENTATIVE SAMPLE OF THE POPULATION	IDENTIFICATION OF STRESS FACTOR	SPECIES	REFERENCE	APPLICABLE TO CARRYING CAPACITY?
Muscle strength	Dynamometric	General	Scallop sp., clams, oysters	Maguire *et al.* 1999	Y
Byssus production	Time for vertical realignment, by byssus production or behaviour	Depends on general environmental factors	Mussel sp., scallop sp.	Clark and MacMahon, 1996; Dolmer, 1998; Etoh *et al.*, 1997; Moles and Hale, 2003; Stern and Achituv, 1978	Y
Valve closure	Visual observation or recording of valve gap or time of closure	Food availability, disease agent, environmental factors	All bivalves molluscs	Dolmer,1998; Higgins,1980; Jorgensen *et al.*, 1988; Kramer *et al.* 1989; Loosanov, 1942; Tyurin, 1991	Y
Mantle recession/ Colouration of mantle, gill condition	Observation, light microscopy, chemical analysis	Disease, pollutant	All bivalves molluscs	Strand *et al*,. 1993	?
Shell condition	Observation of shape, integrity and colour, percussion test	Shell growth, fouling, presence of parasite or their effect, pollutant, environmental factors	All shellfish	McDuffy *et al.*1999 Grefsrud & Strand, 2006;	N
Change in meat content	Condition indices from industry	Environmental & ecological factors	All mollusc species	Crosby and Gale, 1990, Gee *et al.*, 1977, Leavitt *et al.*, 1995; Marcus *et al.*, 1989; Molares *et al.*, 1986; Reiner and Mann, 1992.	Y
Mortality	Frequency of recent empty shells, Survival in air, stress on stress	General	All molluscs	Eertmann et al., 1993; Viarengo and Canesi, 1991; Wells and Baldwin, 1995; de Zwaan et al., 1995	Y
Behaviour	Burrowing time or depth	General	Infauna	Fleury *et al*, 1996; Hulscher, 1973; Maguire et al;, 1999	?
Physiology	Scope for growth, cardiac activity	General	All molluscs	Coleman,1974; Depledge and Andersen, 1990; Smaal and Widdows, 1994	?

Table 2. List of existing biochemical/cell-based techniques used to evaluate stress in shellfish from the literature. Data are from references gathered from Abstracts from Fisheries and Aquatic Sciences (ASFA) in May 2004. Some references on species other than bivalve molluscs are included to show that the indicator is generic across phyla.

MEASUREMENT	SPECIES	COMMON NAME	STRESSOR	SOURCE
Heat Shock Proteins - HSP70	*Cherax quadricarinatus*	Australian crayfish	Temperature	(Cimino et al. 2002)
	Penaeus monodon	Tiger shrimp	Temperature	(Cimino et al. 2002)
	Haliotis rubra	Blacklip abalone	Temperature	(Drew et al. 2001)
	Haliotis midae	S. African abalone	Temperature, ammonia	(Reddy-Lopata et al. 2000)
	Crassostrea virginica	American oyster	Heavy metal, PCB, temperature, disease agent	(Brown et al. 1993); (Cruz-Rodriguez et al. 2000)
	Crassostrea gigas	Pacific oyster	Temperature	(Shamseldin et al. 1997)
	Stylophora pistillata	Branching coral	Temperature	(Tom et al. 1999)
	Geodia cydonium	Sponge	PCB's	(Wiens et al. 1998)
	Mytilus galloprovincialis	Gallo mussel	Temperature, bacteria	(Tiscar et al. 1996)
	Mytilus edulis	Blue mussel	Temperature, cadmium	(Brown et al. 1995)
	Gammarus duebeni.	Amphipod	Cadmium	(Brown et al. 1995)
Metallothionein	*Mytilus edulis*	Blue mussel	Heavy metals	(Steinert & Pickwell 1988)
	Macoma balthica	Baltic clam	Heavy metals	(Bordin et al. 1997)
	Corbicula fluminea	Asiatic clam	Heavy metals	(Baudrimont et al. 1997)
	Ruditapes decussate	Clam	Cadmium, heavy metals	(Bebianno et al. 1993)
	Mya arenaria	Soft-shell clam	Cadmium, manganese	(Blaise et al. 2002)
Neutral lipids	*Mercenaria mercenaria*	Hardshell clam	Starvation (larvae)	(Gallager & Mann 1984)
	Crassostrea virginica	American oyster	Starvation (larvae)	(Gallager & Mann 1984)
	Ostrea edulis	European oyster	Starvation (larvae)	(Gallager & Mann 1984)
	Macrobrachium borellii	Shrimp	Starvation	(Pollero et al. 1991)
Neuroendocrine	*Crassostrea gigas*	Pacific oyster	Shaking, temperature, salinity	(Lacoste et al. 2001b)
	Eledone cirrhosa	Octopus	Air exposure	(Malham et al. 2002)
Haemocytes (phagocytosis)	*Eledone cirrhosa*	Octopus	Air exposure	(Malham et al. 2002)
	Crassostrea gigas	Pacific oyster	Antigen,	(Lacoste et al. 2002)
	Crassostrea virginica	American oyster	Temperature, salinity, TBT, metals, bacteria	(Volety et al. 1999), (Tirard et al. 1997), (Oliver et al. 1995)
	Panulirus cygnus	Spiny lobster	Handling, starvation	(Jussila et al. 2000)
	Ruditapes philippinarum	Clam	Bacteria, starvation	(Oubella et al. 1993)

3.7 Preliminary tool to diagnose stress leading to mortality in shellfish

The tool presented below is not complete, and should be subject to peer review by scientists engaged in this field of study and subsequently revised and enhanced.

3.7.1 Diagnosis

The three primary responses to stress that manifest themselves in shellfish populations are broadly defined as follows;

1) Declining condition - mortalities occurring after observed/measured changes in the condition (health, performance) of the stock. In addition, abnormal behaviour and shell growth is also be included in this definition. The time-scale for the change may be short (immediately prior to mortality event) or may be a long-term trend (e.g. declining annual stock yield). The declining condition can either be detected by visual observations, or by more sophisticated methods such as biochemical analysis.

2) Acute mortality - the loss of a significant percentage of the standing stock of cultured bivalves without any previous sign that a potential problem existed with the stock.

3) Loss - the observation of little or no trace of the cultured bivalves, or of bivalve tissue, remaining on site.

For each category, we have attempted to describe the observed problem and relate that to a known or possible cause and suggested some follow-on investigations or observation that might be effected by the shellfish farmer and the regulatory agency. In all cases it is important that as much information as possible be described and recorded by all involved in the diagnosis. In addition, information on how to pack and send samples and where to send them, such that they are identifiable as well as a summary of case details should be provided.

To aid the farmer and manager in identifying the cause of the problem we have formulated a series of questions that will direct the user to a specific table. With this table the problem can be diagnosed, or the need for additional samples can be identified.

1) Are there any cultured shellfish still present?
   - 1.1) If yes, go to Question 2.
   - 1.2) If no, go to Table 3.

2) Are the shellfish dying?
   - 2.1) If yes, go to Table 4.
   - 2.2) If no, go to Question 3.

3) Are there visual abnormalities in whole animal, shells or tissue or are there changes from the long term mean detected with the monitoring programme?
   - 3.1) If yes, go to Table 5.
   - 3.2) If no, go to Question 4.

4) Are the observed changes predicted?
   - 4.1) If yes, take appropriate action.
   - 4.2) If no, go to Table 6.

Table 3. Possible causes of loss of cultured shellfish with some recommended follow-on investigations.

OBSERVATION (RESPONS)	POSSIBLE CAUSE (STRESSOR)	FOLLOW-ON INVESTIGATION
Shell fragments	1. Predation 2. Storm events 3. Ice damage	1. Look for predatory organisms 2. Review weather recordings and any information on currents and waves 3. Review records of ice distribution and movement 4. Resite shellfish as preventative measure if confirmed
high degree of fouling on remaining stock	Increase hydrodynamic stress resulting in fall-off.	Assess extent and type of fouling, review environmental conditions (storm events), review temporal and spacial setting of collectors and measure success
Reduced attachment strength of remaining stock	Parasites (trematodes)	Send sample for analysis
Reduced burial depth of remaining stock	1. Parasites (trematodes) 2. Salinity	1. Send sample for analysis 2. Measure salinity and review recent data
Change in size distribution of remaining stock	Selective mortality by age or reproductive stage	Measure representative number of shellfish or take surrogate measure of size (volume count), review environmental records (e.g. temperature and salinity).
Morphometric shell differences within a population or year class	Speciation Density-dependent responses to space limitations	morphometric and molecular analysis

Table 4. Possible causes of acute mortality in cultured shellfish with some recommended follow-on investigations.

OBSERVATION (RESPONS)	POSSIBLE CAUSE (STRESSOR)	FOLLOW-ON INVESTIGATION
Recent empty shells	predation diseases parasites	look for predatory organisms (e.g. birds, crabs, nemerteans) send a sample for physiological and biochemical investigations, watch for holes and blisters in the shell,
Shell fragments	Predation	look for predatory organisms (e.g. birds, crabs)
Sulphur smell, external shell blackening	anoxic event algal bloom	measure O_2 concentration in water column and review environmental recordings (if available). Note evidence of other dying organisms (e.g. fish, invertebrates). Bacterial identification. take water sample and send for further investigations (Chl analysis, taxonomy), measure O_2.

Water discolouration	algal bloom sediment load	take water sample and send for further investigations (Chl analysis, taxonomy), measure O_2. 2. record secchi depth, take water samples for total suspended solids analysis.
Clogged gills	1. algal bloom 2. sediment load	1. take water sample and send for further investigations (Chl analysis and taxonomy). 2. observe if there is sediment obvious on gills or send a tissue sample for further investigation.
Burial	1. sedimentation 2. storm event 3. dredging	1. review weather recordings (strong currents and waves, tidal stage), evidence of shoreline erosion, increased riverine discharge. 2. review weather recordings (strong currents and waves) 3. consult with fishermen regarding fishing activities, investigate other activities (marine construction, dredge spoil disposal) in the region.

Table 5. Possible causes of declining condition in cultured shellfish with some recommended follow-on investigations.

OBSERVATION (RESPONS)	POSSIBLE CAUSE (STRESSOR)	FOLLOW-ON INVESTIGATION
	Whole animal	
Shell gaping, mantle recession, discolouration (see Table 1a)	1. Low oxygen Pathogen high temperature	Measure O_2-concentration in water column or, if available, review temperature and O_2 recordings. Note evidence of impacts on other organisms (e.g. fish, invertebrates) Collect whole animal samples for analysis. Collect tissue samples for analysis (e.g. heat shock proteins, see Table 2)
Enlarged size of siphon openings or closed shells	Low food availability	Take water sample and send for further investigations (Chl and total solids analysis and taxonomy). Collect tissue samples for analysis and compare to seasonal data (e.g. lipids or glycogen, see Table 2)
Reduced attachment strength (see Table 1a)	Parasites (trematodes)	Send sample for analysis
Reduced burial depth (Table 1a)	1. Parasites (trematodes), 2.Shallowing of sediment oxic layer 3. low salinity	1. Send sample for analysis 2.Discolouration and smell of sediments, bacterial mats developing. Send samples for Eh, sulphide analysis. 3. measure salinity and review recent data
Shell righting behaviour in scallops, shell closure time in mussels	High temperature Disease / parasites Low oxygen	1. Collect tissue samples for analysis (e.g. heat shock proteins, neuroendocrine levels, see Table 1b) 2.Collect whole animal samples for analysis 3.Measure O_2-concentration in water column or, if available, review temperature and O_2 recordings. Note evidence of impacts on other organisms (e.g. fish, invertebrates)
	Shell condition (see Table 1)	

OBSERVATION (RESPONS)	POSSIBLE CAUSE (STRESSOR)	FOLLOW-ON INVESTIGATION
Shell structure	1. Physical restriction (e.g. overcrowding) 2. Contaminants 3. Speciation 4. Invasion by parasite	1. Measure organism stocking density and correlate with presence of abnormalities 2. Send sample for body burden analysis (e.g. TBT causes bullet shape in oysters, metallothionein level gives indication of heavy metal pollution and heat shock protein give indication of heavy metal pollution in *C. gigas* and *M. edulis*, see Table 2) 3. Send sample for taxonomic analysis 4. Send to health expert for diagnosis
Reduced growth rate of stock	1. Food and space competition (e.g. fouling, overstocking) 2. Ill health	1. Review history of culture activity focusing upon potential competing organisms and culture density 2. Send to disease diagnostician, send to diagnostician
Reduced shell thickness	1. Food availability and quality 2. Speciation	1. Take sample for chlorophyll, total suspended solids and organic content. Review. information on stocking density and hydrodynamic regime. 2. Take samples for taxonomy analysis
Shell colour (internal and external)	1. Parasites 2. Disease	1. Check for shell blisters or holes, send sample for analysis 2. Send sample for analysis
pearl production	1. Sediment load 2. Parasites	1. Note any discolouration of the water, measure Secchi depth, review information on sediment load (run off, erosion, dredging). Collect water samples for total suspended solids analysis. 2. Send sample for analysis.
Tissue condition		
Low meat yield (sse Table 2)	1. Food availability 2. Parasite infection 3. Speciation, low meat yield	1. Review history of culture activity focusing upon potential competing organisms and culture density as well hydrodynamic regime. Take sample for chlorophyll, total suspended solids analysis, POC and TON measurement.and phytoplankton taxonomy and size structure. Collect tissue samples for analysis and compare to seasonal data (e.g. lipids or glycogen, see Table 2), or test scope for growth (see Table 1) 2. Test for paraasites (e.g. *Mytilicola* sps) 3. Send to diagnostician
Abnormal meat colour	1. Disease 2. Food	1. Send sample for analysis 2. Take sample for determination of algal species composition
Abnormal gill condition	1. Parasite or disease 2. Sedimentation	1. Send sample for analysis 2. Discolouration of the water, secchi depth, information on sediment load (run off, erosion, dredging)
Abnormal mantle condition	Parasite (pea crab, trematode), disease	Check for presence of pea crabs. Send sample for analysis.

Table 6. Measurements to check for risks of declining condition in cultured shellfish when no visual abnormalities in whole animal, shell or tissue are present.

POSSIBLE CAUSE	INVESTIGATION
Chemical contaminants (e.g. pesticides, heavy metals, drugs).	Send sample for analysis (see Table 2).
Physical changes (e.g. global warming)	Send sample for analysis (see Table 2). Review historic data.
Habitat change (e.g. increased river run-off)	Review long-term data
Genetics (e.g. inbreeding, reduced fitness)	Genetic analysis, test for heterozygosity (Tremblay, 1998)
Disease (intracellular infection, e.g. Bonamia)	Histology, molecular tests

3.7.1.1 Background information

In order to determine the extent of the problem and also to help identify the cause, answers to the next three questions may provide important background information.

How widespread is the problem?

This question can be addressed from two perspectives. What is the geographic extent of the problem or what is the scale of impact on culture operations (i.e. is it confined to one lease or multiple leases)? The scale of impact may be defined into a number of categories;

- Local – examples could be individual shellfish, part of culture unit (including vertical distribution), whole culture unit, multiple farms within a defined area;
- Regional – part of bay, entire bay, multiple connected bays;
- National - throughout the most parts of the country or the majority of shellfish culture areas;
- International – trans-boundary encompassing two or more nations.

It is likely that, if the problem extends beyond the local or regional scale, this information may best be compiled by the resource managers or a regulatory agency, through epidemiological investigations. It is essential that good communication exists between producers and their organisations and the regulatory management agencies to control and limit the spread of the problem. Identification of the scale of the impact will help direct the response from both the shellfish farmer(s) and the regulatory/management agencies. It will help identify measures of control, prioritise research and investigation as well as provide resources needed to carry out such efforts.

When does the problem occur?

Does the problem manifest itself on a seasonal basis or periodically throughout the year (i.e. related to a regular pattern such as a tidal forcing), or is it random in time and not demonstrating any temporal patterns. An example would be an exposure of a shellfish population to a stressor (e.g. high temperature) during a period of high energy demand (reproduction) by the shellfish, which could lead to mortality in the populations.

Where does the problem occur?

Is the problem related to a specific culture type or originate and spread from wild populations:

- on-bottom (e.g. clams in sediment or mussels on culture plot);
- off-bottom (e.g. oysters in bags and trestles);
- suspended (e.g. rope mussel culture);
- intertidal; or
- subtidal.

In addition, location of the culture operation within a bay might also have a bearing on the cause of any mortalities. An example would be whether an activity is located at the mouth or the head of the bay. This could possibly expose the cultured organisms to a range of hydrodynamic and food conditions with different consequences to the culture animal.

Different culture conditions or hydrodynamic conditions will expose the culture animals to a range of different stressors. Such information could be crucial in determining the direction of the response, in particular the type and extent of further investigation that might be required. A change in situation, culture type, or a change in the species culture type may alleviate the problem. For example, a species susceptible to serious disease (*Ostrea edulis* in the case of Bonamia) may be replaced by a non-susceptible species (*Crassostrea gigas*).

3.8 Discussion

There have been many research projects aimed at determining methods to assess stress in both isolated organisms and in the environment as a whole. More are being published every day. The usefulness of some of these techniques will depend heavily on the analytical equipment available and the cost: benefit ratio of the particular test compared to the economic cost of the problem. Despite the wide array of techniques available, there are some generalisations that can be made on the applicability of the various approaches and the list of potential users.

In general, changes to the stress level of an organism start at the molecular level and then move up through the cellular, tissue, organ and then the entire organismal structure of the organism. The variability and temporal nature is inversely related to the scale of the effect. For example the variability in the concentration of some stress proteins may be large as the concentrations increase and decrease quickly with a short-lived stressor. Conversely, the effect of the same short-lived stressor may be undetectable on the organs or the animal as a whole. As a result there are three broad categories of stress indicators in shellfish that have been developed. The first is behavioural tests in comparison to a reference value. These involve the organism as a whole and may involve self-righting tests, speed of movement or shell closure times. A second broad category is the morphometric measurements. This category would address systemic changes at the organ or tissue level and commonly involve measurements of tissue weights, shell dimensions, histological areas etc. in relation to known baseline relationships. The third category involves changes at the cellular level. Various biochemicals are analysed and the concentrations are compared to known baseline standards, or biochemical tests applied to detect the presence of a stressor organism. These biochemicals (including certain cell types) are proxy measurements for physiological functions such as the endocrine, pulmonary, reproductive or other systems that are operating within the organism. The usefulness of these biochemical indicators depends on the scale of prediction needed. It would be an entirely different question to ask if the effects of a particular biochemical concentration could be predicted for the next 5 minutes or the next 5 months.

The implications of this change in variability with scale suggest that a bio-security program needs to decide at what scale of effect it wishes to detect and at what level of practicality. The first point of observation will be during the monitoring phase at the farmer level. The shellfish will be observed in situ and either the farmer or monitoring team will begin with behavioural observations. As described above, these observations represent an accumulation of inputs to the animal and as a result may not represent current conditions, however they are practical, data generation is immediate and can be handled easily by the farmer. In order to go further, morphometric measurements would have to be taken. Samples can be easily collected during monitoring surveys, but there is some post sampling processing that will have to be required. This can be done by individual farmers, but are often coordinated through associations or resource agencies. Costs are relatively higher than the observational measurements. The last category is the small scale biochemical measurements. These are often taken from specially preserved tissue samples and are generally done in analytical laboratories. The equipment required to do the analysis is expensive and the time required to generate data can be quite long. These samples are the most expensive to deal with and should likely only be considered when more detail analysis of samples is justified.

In the case of disease diagnosis, general tests such as histological examination (available to all countries to ensure a level playing field) are employed. These can detect various effects on a variety of tissues by a range of pathogens. By comparison, fast, specific tests such as in situ hybridisation are employed to confirm the presence of a pathogen. New, sensitive and inexpensive tests should continue to be developed employed universally to ensure efficient and effective detection of pathogens thus minimising their impact. In the case of HABs, much discussion is currently underway to change from the universally employed mouse assay to a quicker and more efficient chemical test for PSP.

It is appreciated that mortality events in cultured shellfish populations can be as a consequence of multiple stressors acting in unison or in sequence (WGPDMO, 2005). This exercise attempts to recommend a framework and diagnostic tool to aid in the identification of causes of loss, acute mortality or a reduction in performance or condition of shellfish. WGMASC appreciates that the tool is not complete, and should be subject to peer review by scientists engaged in this field of study and subsequently revised and enhanced. However, it does provide a preliminary diagnostic tool that strongly recommends the inclusion of the shellfish farmers in the information generation and detection process. If a specific stressor cannot be identified by these preliminary queries, the information generated can form the basis of a case study to inform more comprehensive diagnostic testing (e.g. disease and/or physiological test).

The WGMASC advises the development of industry codes of practice in order to ensure good communication is established with competent authorities who may need to employ further testing (e.g. chemical or molecular tests) and have the expertise to evaluate the test results, assess the weight of evidence provided and report efficiently to the farm, such that advice can be given and appropriate action taken.

Written protocols, perhaps based upon the questions outlined above, should provide guidance on how to pack and send samples, who and where to send them, such that they are identifiable, and arrive at the right place and in good condition with an enclosed brief summary of case details. It is then imperative that laboratory results are obtained efficiently and to a good standard, offering a diagnosis, and if possible, information on how to tackle the problem(s). The desired aim of these diagnostic measures is the production of a fast growing, healthy, marketable product, which these measures should help to promote.

3.9 General Conclusions

1) Diagnosing shellfish mortality through the application of a coordinated monitoring program and hierarchical problem-solving protocol would be a valuable tool to the expanding shell culture industries from a production and management point of view. Baseline data on these stress indices should be generated to enable comparison of the various systems;

  1.1) by communication with, and inspection of, farm sites, routine monitoring by site staff guided by environmental and fish health experts, driven by industry or legislation.

  1.2) by collection of data under contract with university or by the official authority. The data should be collected uniformly by country to allow comparison and similar action by the state, as necessary.

The operating principle of the process is to work initially from the farm-scale observations on coarse spatial and temporal scales that are conducive to being done by the farmers or local monitoring programs. As the requirement for increased types of observations and resolution for problems are identified, then more sophisticated measurements will be made recognising that the relative costs and analytical time will significantly increase.

A series of reference tables outlining the various symptoms and potential causes based on available information in the literature is a valuable tool to diagnose the problem.

One of the benefits of a standardised system for monitoring would be the ability to compare trends of shellfish performance indicators by industry and managers from adjoining regions, whether they are national or international.

1) To make the diagnostic tool to aid in the identification of causes of mortality in cultured shellfish operational a few more steps need to be taken. First, the tables need to be reviewed by experts to make sure that all available data are included. Second, the shellfish industry must have a look at it to see if it fits their needs. Third, an illustrated leaflet needs to be produced in the languages of ICES countries that culture shellfish. And finally the leaflet need to be distributed to the farmers (e.g. through producer organisations) and the local managers.

2) The development of fast, general & specific and inexpensive diagnostic tests should be a priority for the community, to help minimise the impact of such problems.

3.10 Recommendations

The Working Group recommends to the Mariculture Committee that this ToR be considered finished from the perspective of the WGMASC. Further work is still required to bring the output from the ToR to an operational state, but this can be done outside the formal ICES WGMASC Working Group.

The Working Group recommends to the Mariculture Committee that this ToR report be circulated to other affiliated MCC Working Groups for review (WGEIM, WGPDNO).

The diagnostic tool should be published and distributed to the farmers (e.g. through producer organisations) and the local managers in the languages of ICES countries. We recommend, as a first step, that an ICES Cooperative Research Report be prepared on this topic. This report would be available to farmers, resource management and scientists and can serve as the foundation for additional discussion among experts and input from stakeholders that could lead to preparation of regional leaflets by responsible authorities.

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4 Complete the development of a recommended framework for the integrated evaluation of the impacts of shellfish aquaculture activities in the coastal zone (ToR b)

4.1 Background

There are many components and tools that need to be developed and integrated into an ecosystem management framework for the evaluation of shellfish aquaculture impacts on the coastal zone. Components include: hazard identification; environmental exposure and risk assessments (including predictive modelling); risk management; cost-benefit analysis; environmental indicator monitoring; effects management based on indicator threshold values, implementation of mitigation measures and utilization of decision support tools for responsive ecosystem management; and communication. Addressing this ToR therefore required the development of a multi-year work plan and the progressive annual reporting on components of the recommended ecosystem management framework for shellfish aquaculture. The following sections continue the work initiated in 2006, where a list of principles and criteria were reported for objectively assessing the applicability of a wide range of ecosystem status indicators and thresholds of concern as benchmarks in the specific management of shellfish aquaculture.

It is not solely the responsibility of scientists to determine a framework for the integrated evaluation of the impacts of shellfish aquaculture activities in the coastal zone. Socioeconomic considerations are also paramount in setting many critical decision criteria (e.g. what constitutes an unacceptable impact and what is the threshold of potential public concern?). Our role as scientists is to provide the requested advice from the perspectives of providing recommended science-based approaches for:

1) characterizing ecosystem status and aquaculture impacts (e.g. effective indicator identification);
2) characterizing the potential consequences to marine ecosystems from changes in this status (e.g. threshold recommendations);
3) identifying effective measures for mitigating any observed impacts; and
4) facilitating management decisions (e.g. decision-support tools).

This implies that we do not consider the potential consequences to industry or society stemming from our recommendations related to this ToR. However, such socioeconomic considerations are highly relevant to the development of an aquaculture management framework, but were considered to be outside the scope of our activities and expertise. Furthermore, environmental conservation and protection legislations in place within ICES countries are clearly important considerations for the selection of indicators, and particularly for the setting of management triggers/thresholds. These are reviewed in a Section 4.6 in the context of Integrated Coastal Zone Management (ICZM) activities in many ICES countries.

4.2 The use of indicators in the integrated evaluation of the impact of shellfish aquaculture

4.2.1 Definitions and concepts

A definition of the term "indicator" is based on Vos et al. (1985), as cited by Gilbert and Feenstra (1994) and explained as follows, "In measurement theory the term "indicator" is used for the empirical specification of concepts that cannot be (fully) operationalized on the basis of generally accepted rules". Some examples of concepts for which indicators are used as surrogate measures include; ecosystem status, ecosystem health, environmental performance (also seabed or water-column performance), and functional sustainability performance (Rice, 2003, Gibbs, 2007). Gibbs (2007), in his review of indicators for suspended bivalve culture, noted that the indicators should identify where present levels of culture may be in relation to the following milestones:

- no significant change in ecological processes, species, populations or communities within the growing region (i.e. the culture has not exceeded the ecological carrying capacity as defined by Gibbs, 2007);
- the culture controls phytoplankton dynamics in the growing region; and
- the culture is at the production carrying capacity (Gibbs (2007) defines this as the maximum sustainable yield of culture that can be produced within a region).

The function of indicators primarily lies in simplification, meaning that they are a compromise between scientific accuracy and the demand for concise information. The indicators may be used for problem identification, planning, allocation of socio-economic resources, policy assessment, etc. But in this case the primary purpose will be for evaluating the livestock farming system i.e. assessment of sustainability. It should be underlined that the important relation to scale, i.e. farm, community, region etc., is not discussed, in the paper, although it is very important for the evaluation of the influence aquaculture has on its surrounding.

Gilbert and Feenstra (1993) have on the basis of the literature identified four desired features of indicators:

1) the indicator must be representative for the system chosen and must have a scientific basis;
2) indicators must be quantifiable;
3) a part of the cause-effect chain should be clearly represented by the indicator; and
4) the indicator should offer implications for policy.

More detailed characteristics, or criteria, for desirable global sustainability indicators are given by Liverman et al. (1988).

Some concepts from the sustainability literature are worth remembering when assessing the relevance of indicators in a given context. Several authors have pointed out that an indicator cannot usually be made from a simple parameter. A chemical measurement or abundance generally does not prove to be effective indicator. For example, an isolated winter measurement of chlorophyll a is not relevant to indicate the local level of eutrophication (Bricker et al., 1999), whereas an extreme statistic computed from data sampled at high frequency in an exposed site at risk season, say end of spring, will better reflect this phenomenon. Thus, as stressed by Nicholson and Fryer (2002), the term “indicator” implies the relevance of the parameter, i.e., the linkage to the question or set of questions generating the need for the indicator(s). In the previous example, there is a direct relationship between chlorophyll a and coastal nutrient enrichment. The indicator-statistic, for example, a slope in Nicholson and Fryer (2002), and the associated metrics, i.e., the unit in case of a quantitative indicator, are necessarily parts of the indicator concept.

A parameter or set of parameters, or an ”index” or a ”score”, are considered a good indicator only after it has been validated to effectively indicate what it was designed for. There are two nested conditions for this: (1) the appropriate mathematical approach must be defined that will transform quantitative or qualitative data into numbers that can be compared to threshold values in a predefined classification system; and (2) the information collection process (i.e. sampling design), consistent with the former condition, must be precisely defined to provide reasonable statistical power for effectively detecting an impacted area.

4.2.2 The different frameworks

Indicators are often presented within already established frameworks. Frameworks for the indicators produced are often built in a given social context (Olsen 2003). They also depend on the spatial or economic scale considered (Spangenberg 2002; Rochet and Trenkel 2003). Using frameworks to present sets of indicators should be useful for the following reasons (Segnestam 2002):

- Indicator frameworks provide the means to structure sets of indicators in a manner that facilitates their interpretation.
- Indicators are usually needed for many aspects of a problem or issue, and the framework selected ensures that all of those aspects have been taken into account.
- Frameworks can also aid the understanding of how different issues are interrelated.

Three different types of frameworks for presenting indicators are generally recognised (OECD 2000):

1) **Project-based frameworks** (also referred to in the literature as the Input-Output-Outcome-Impact framework), which are used in the monitoring of the

effectiveness of projects whose objective it is to improve the state of the environment.

2) **Driving Forces–Pressure -State-Impact-Response (DPSIR) frameworks** originally developed by the Organisation for Economic Cooperation and Development (OECD) for national, regional and international level analyses, and are now in use in the European Environment Agency (among other international institutions).

3) Frameworks that are based on environmental (or sustainable development) themes (e.g.: Pelagic/benthic; communities and species; flows of carbon/nitrogen; loss in diversity; economic damage; intensive vs. extensive aquaculture; open or closed environments; hydrodynamics…)

4.2.2.1 The DPSIR frameworks

The DPSIR framework (Fig. 3) is becoming widely used, as it allows coverage of a large spectrum of particular situations, as long as the environment is concerned. This framework was originally derived from the social studies and has subsequently been widely applied internationally, particularly for organising systems of indicators for managing environment and sustainable development. A full description is given by the Organisation for Economic Cooperation and Development (OECD). The first version of this framework is called the Pressure-State-Response (**PSR**) framework that states that human activities exert *pressures* on the environment, which can cause changes in the *state* of the environment. Society then *responds* with environmental and economic policies and programs intended to prevent, reduce or mitigate pressures and/or environmental impact.

The first variation of the PSR framework replaces the pressure indicator category with a category of driving force indicators, creating a Driving Force - State - Response (**DSR**) framework. The driving force component includes human activities, processes and patterns that impact on sustainable development, and is intended to better accommodate socioeconomic indicators. The second variation adds a category of impact indicators, transforming it into a Pressure-State-Impact-Response (**PSIR**) framework. The latest version, which has become widely employed, is the **DPSIR** framework. In this framework, the Driving forces, produce Pressures on the environment, which then degrade the State of the environment, which then Impacts on human health and eco-systems, causing society to Respond with various policy measures (Fig. 2). When producing a set of indicators related to the impact of shellfish farms, most of these indicators will probably be related to the State and Impact categories.

4.2.2.2 Other frameworks relevant in assessing the Impact of shellfish aquaculture on marine environments

Considering the impact of aquaculture on marine environments, a framework based on the type of shellfish culture, may be relevant. Also of interest is an ecosystem based framework, which is best utilised when considering the need for an ecosystem approach. To cope with the particular aspects of the impact of shellfish culture, it is suggested that an environmental framework includes the following themes, which correspond to the main impacts observed in marine environments:

1) impact on seabed geophysical properties, geochemical processes and the structure and ecological role of benthic flora and fauna (i.e. indicators of seabed status and benthic performance),

2) indicators of water-column interactions with shellfish culture (i.e. indicators of water quality and pelagic ecosystem function indicators),

3) the cumulative ecological effects of any pelagic and benthic interactions with shellfish culture,

4) coastal zone management, including the synergistic and/or antagonistic effects of all anthropogenic activities in the region,

5) potential genetic implications of culture activities, and

6) socio-economics aspects.

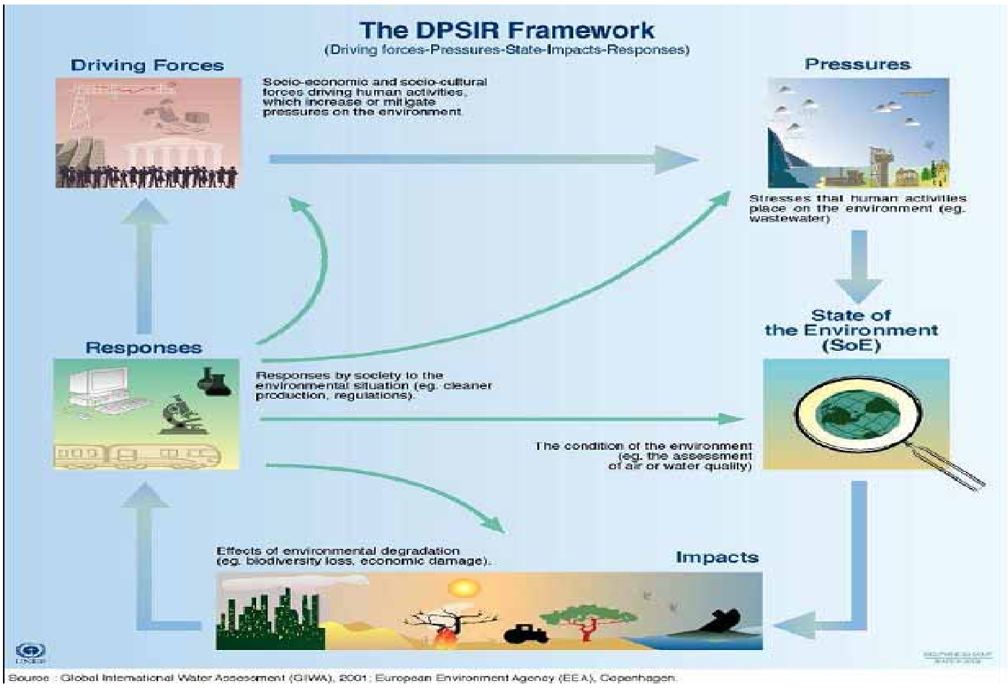

Figure 2. Schematic diagram of the DPSIR framwork.

4.2.3 Slow and fast variables as indicators

There are "fast" and "slow" variables that can be employed as indicators of the effects of shellfish aquaculture on marine ecosystems. Slow response variables are frequently important driving forces for dynamic interactions in an ecosystem (e.g. semi-enclosed estuaries with little tidal range versus oceanic conditions), while fast variables describe component dynamics that iterate more rapidly (e.g. phytoplankton growth). Slow variables, such as currents and residence time in a water body, provide the context for the dynamic interactions of fast response variables of a system. Component relationships between these types of variables (i.e. between ocean currents, productivity and production output of shellfish) have to be integrated to capture intrinsic local-specific properties. A number of conditions and processes among the slow variables act as basic drivers of change. For instance, while ocean currents are not inevitably persistent, they certainly condition the initial direction of economic, social and environmental change and may strongly influence even the long-term future. However, unlike fast variables, the slow variables often are not easily manipulated for management purposes. For both types of variables, it is important to describe the relationship of all indicators to the functioning of the ecosystem and the type(s) of shellfish aquaculture operation.

4.2.4 Assessment of indicators

Not one universal set of indicators is applicable in all cases (Segnestam, op.cit.). However a small set of well-chosen indicators tends to be the favourite choice of most indicators users, including the stakeholders for aquaculture. A number of selection criteria can be applied when there is a need to restrain the number of indicators. Several recent papers have proposed a list of performance criteria for environmental or ecological indicators (Kurtz, Jackson et al. 2001, Rice, 2007) and specifically for fishery indicators (Garcia and Staples 2000) and shellfish aquaculture (Cranford et al., 2006, Gibbs, 2007). Rationale is presented in the following sections for the presentation of indicators based on relevance and effectiveness (Fig. 3; Nicholson and Fryer 2002), as well as on other characteristics.

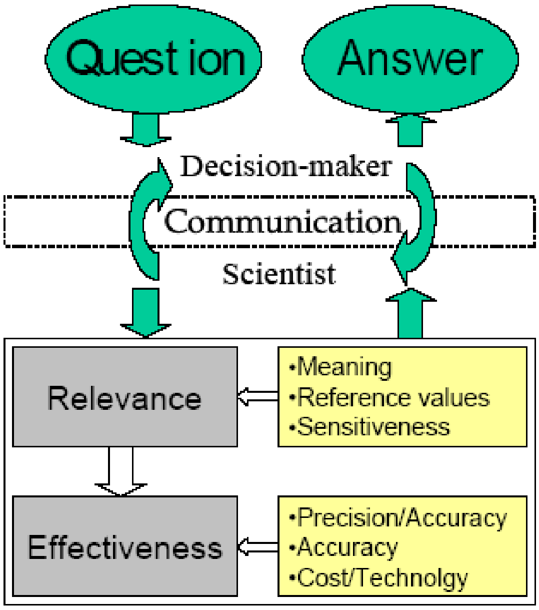

Figure 3. Criteria to be considered in choosing environmental or ecological indicators (from (Nicholson and Fryer 2002).

4.2.4.1 Relevance

For all authors, the relevance or meaning of an indicator represents the first essential phase in the process of indicator selection. There should be a clear or understandable linkage between the indicator and the objective, i.e., what it is supposed to describe? For example, species richness or the number of species by taxonomic group has often been used as an indicator of biodiversity.

4.2.4.2 Effectiveness

This criteria is defined as the indicator ability to respond to variations in forcing, i.e., in pressure. While some indicators may respond to dramatic changes in the system, a suitable indicator displays high sensitivity to particular and, perhaps, subtle stress, thereby serving as an early indicator of reduced system integrity (Dale and Beyeler 2001). Most reference points for population indicators are estimated with unknown precision, and no reference points are available for any of the community indicators.

4.2.4.3 Precision/Accuracy.

Precision, or in an opposite way variability, is referred to as robustness by Garcia and Staples (2000). According to these authors, an indicator is considered to be robust if results are not too variable with regard to random (e.g., between-individual responses) or pseudo-random (e.g., hydro-climatic factors) fluctuations.

4.2.4.4 Feasibility

Trade-offs between desirable features, costs, and feasibility often determine the choice of indicators (Dale and Beyeler, op.cit). Theoretical indicator constructions are useless on an operational basis if adequate data are not available, either due to the fact that the data are technically a very difficult if not impossible challenge to obtain or collecting the necessary information is too expensive.

4.2.4.5 Sensitivity

A good indicator is expected to be both sensitive and precise. Ideally, the indicator has a known substantial response to disturbances, or anthropogenic stresses, and changes over time, and has low variability in response. Monitoring programmes often depend on a small number of indicators and, as a consequence, fail to consider the full complexity of the system (Dale and Beleyer, op.cit.). This is most important for ecological indicators that address the complexity of ecosystems.

4.2.4.6 Clarity

For the same authors, clarity by managers or more generally non-scientists is proposed as an element of indicator selection. Still, the world of indicators seems to be open to conceptual and methodological developments. Progress could be achieved in the use of extreme statistics instead of median or average values, and in the development of methods to combine indicators to improve decision-making.

4.2.4.7 Other

The following list of the criteria proposed by the OECD (OECD 2000) and ECASA partners, can be used for the evaluation of the different indicators related to the impact of shellfish culture on the environment:

- direct relevance to objectives and the target group,
- the indicator selection must be closely linked to the environmental problems being addressed,
- different target groups could have different needs and uses for the information provided by the indicators. Consideration of who the target group consists of is therefore central, and
- clarity in design.

It is important that the selected indicators are defined clearly based on the following criteria to avoid confusion in their development or interpretation.

- *Realistic collection or development costs*. Indicators must be practical and realistic, and their cost of collection and development therefore needs to be considered. This may lead to trade-offs between the information content of various indicators and the cost of collecting them.
- *High quality and reliability*. Indicators, and the information they provide, are only as good as the data from which they are derived.
- *Appropriate spatial and temporal scale*. Careful thought should be given to the appropriate spatial and temporal scale of indicators.
- *Obvious significance*. Such a criteria may overlap with the one on “clarity in design”, but one should remember that the final use of indicators are those of communication tools. Their significance should easily be understood by stakeholders. According to this criterion, the layman should retain the simplest concept and/or presentation for a better comprehension. For example, indicators on levels of oxygen are better understood then those on sulphide concentrations. When possible, the data should be presented quantitatively (0-10 or 0-100, or % saturation O2).
- *Responsive*. For an ecosystem approach to management to be effective, the time-frame between indicator data collection and the decision-making process needs to be as short as possible. Responsive and adaptive management approaches strive to implement mitigation measures quickly so that ecosystem status does not continue to deteriorate. Near real-time indicators therefore have a distinct advantage in such programs, whereas indicators that require considerable work to process samples and interpret data may be less desirable.

4.2.5 A list of potential Indicators

Indicators describing the impact of shellfish aquaculture on the coastal zone and on the ecosystem status were compiled from different sources. Several European contracts were aimed at producing indicators related to the interaction of aquaculture (and shellfish culture) with the marine environment. Examples of attempts to compile indicators related with the sustainable development of marine aquaculture and its impact on marine environment include the MARAQUA (www.lifesciences.napier.ac.uk/maraqua/), Consensus (www.consensus.org) and ECASA (www.ecasa.org) programs. The 2006 Canadian review of potential indicators and associated thresholds aimed at the assessment of shellfish aquaculture impacts on fish habitat has been useful because of the pertinence of the ecosystem approach used (DFO, 2006; Cranford et al., 2006; Chamberlain) et al., 2006). The review by Gibbs (2007) focuses on sustainability performance indicators based on bivalve aquaculture interactions in the water-column (e.g. clearance efficiency, filtration pressure, regulation ratio and depletion footprint).

The culture of bivalve molluscs and their associated rearing structures has the potential to impact the environment in positive and negative ways. The identified effects are generally referred to the consumption of suspended particles, to the increased sedimentation due to the production and release of biodeposits which impacts the sediment biogeochemistry, to the nutrient cycling, and to the structure and composition of the benthic and pelagic communities. These impacts are related to the basic interaction of bivalves with their environment, as illustrated in Figure 4.

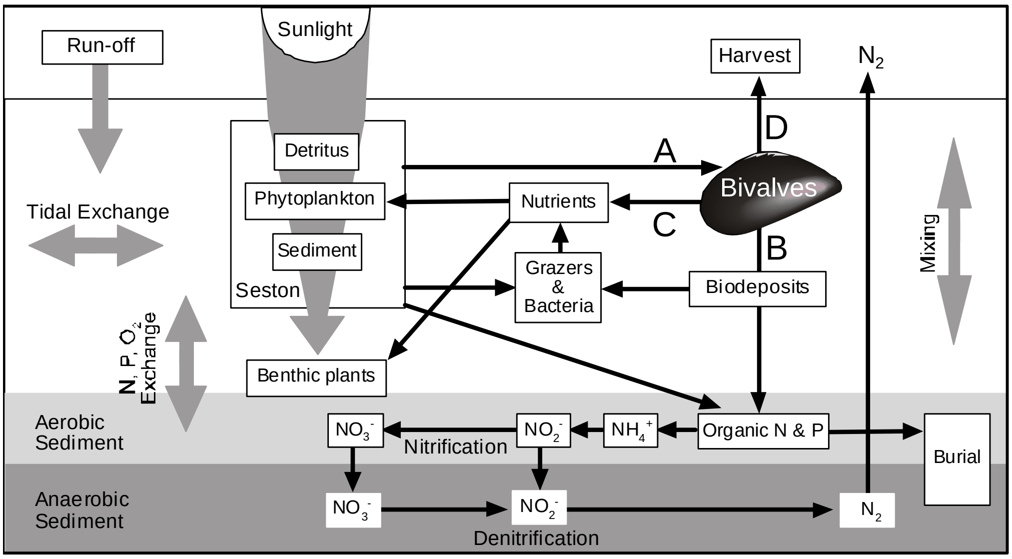

Figure 4. Conceptual diagram of shellfish (bivalve) aquaculture interactions in coastal ecosystems related to: (A) the removal of suspended particulate matter (seston) during filter feeding; (B) the biodeposition of undigested organic matter in feces and pseudofeces; (C) the excretion of ammonia nitrogen; and (D) the removal of materials (nutrients) in the bivalve harvest (From Cranford et al., 2006).

Recommending the use of ecosystem status indicators specific to shellfish aquaculture should be considered in the perspective of a wider ecosystem approach of the shellfish culture. An ecosystem approach may be defined as ‘a comprehensive integrated management of human activities based on the best available scientific knowledge about the ecosystem and its dynamics, in order to identify and take actions on influences that are critical to the health of ecosystems, thereby ‘achieving sustainable uses of ecosystem goods and services and maintenance of ecosystem integrity’ (Rice et al., 2005). Documenting the impact of shellfish culture on the marine environment through the use of indicators is part of such an ecosystem approach, and should be completed with the implementation of recommendations on specific management methods, on assessment, monitoring and scientific research, and on methods of measuring progress towards implementation.

4.2.5.1 Impacts of shellfish culture on the benthic habitat and communities

Benthic impacts are well known as they are spatially limited, and easy to monitor and assess with the current sampling and analytical techniques. They are related to the production of bivalve faeces and pseudofaeces that fall on the sediment. As the biodeposits contain organic matter (15 to 50%), they produce both an increase in the silt content and an organic enrichment of the seabed. The degree of organic enrichment and the resulting impact is site specific, depending on interacting factors, including the hydrodynamics of the system, water depth and residence time, the reared biomass and phytoplankton dynamics.

4.2.5.1.1 Sediment indicators

The main impacts on the sediment are related to the sedimentation of shellfish biodeposits, the resulting accumulation of organic matter, and its mineralization. Some indicators intend to characterise the change in the sediment properties, others address the flux of organic matter to the sediment, and other indicators describe the biogeochemical processes associated with the ecological recycling of the organic matter:

- *Sedimentation rates* as measured by sediment traps. The sediment traps facilitate measurements of the quantity and quality of particulate matter falling from shellfish culture, both in subtidal and intertidal environments. Probably the simplest measurement of the impact of shellfish culture consists of collecting the biodeposits produced by bivalves during a given amount of time. This is a measure of flux of sediment and organic matter to the seabed.
- *Sediment texture* (percent sand-silt-clay) of the sediment is directly influenced by the bivalve culture. The particulate matter is either aggregated as pseudofaeces by the gills of the molluscs or egested as faeces which contain a significant amount of mineral particles.
- *Total organic carbon* in the sediment reflects the amount of organic matter within the sediment, a major part resulting from the biodeposition observed under the bivalve culture. This is usually measured in surface sediment.
- *Total nitrogen* and organic nitrogen in sediment.
- *Sediment carbon quality indicies* including % carbon (inorganic-organic matter), C:N ratio and the Rp index. This Rp indicator (Kristensen 2000) is based on the ratio of a measure of the labile organic carbon, as estimated by the losses on ignition a t 250°, and a measure of the refractory organic matter, after ignition at 500°C, and seems to be sensitive to the molluscs biodeposition (ECASA results).
- *Redox and Eh in surficial sediment*. Low values of the redox potential are linked with the anaerobic degradation of the organic matter into the sediment. It is best measured through vertical profiles into the sediment, which allows the thickness of aerobic and anaerobic conditions to be determined, as related with the quantity of organic matter.
- *Total sulfides* in surface sediment, which is related to oxygen content and biodiversity.
- *Dissolved oxygen consumption* rate in sediment is a measured of the degradation of the organic matter in the upper, oxic layers.
- Other measurements can be performed on the *pore water gradient* of mineral, dissolved nutrients produced during the oxidation process, such as Ammonia, total nitrogen, total phosphorus, and sulphates.
- *Benthic/pelagic fluxes* of sulfate and ammonia.
- *Trace metals* in sediment under finfish farms have been observed to increase. As these products seem to originate from the food, their pertinence in the case of bivalve culture needs to be demonstrated.

- Some *biomarkers* are candidates as indicators of the impact of shellfish culture. (Biesen and Parrish 2005) have shown that the mono-unsaturated fatty acid content is higher in sediment beneath fish farm. Again, this needs to be demonstrated in the case of bivalve culture.
- The *chlorophyll pigments in surficial sediment* can be investigated as an indicator of the impact of shellfish farms in low energy environments. A fraction of phytoplanktonic cells is not digested by the bivalves and can accumulate beneath the facilities.
- *Nitrifier and denitrifier bacteria* population abundance and activity
- *Sediment profile imaging*. Vertical profiles images sediment beneath aquaculture operations show changes in sediment colour and organism distributions indicative of organic enrichment effects.

4.2.5.1.2 Benthic communities indicators

The changes of the texture and biogeochemical properties of the sediment result in a modified habitat, and the ecological communities are reacting to these changes. The biomass can be affected. Sometimes biomass may increase because of the input of organic matter, but it can also decrease when higher organic input, resulting from stress on different species. Ecological diversity can also be affected, and a reduction in the number of species may be observed according to the conceptual scheme established by Pearson and Rosenberg (1978).

The most basic community indicator consists of observations of the presence/absence of macrofauna under the shellfish installations. A total absence of benthic species under shellfish culture has never been reported. Therefore, this indicator does not seem to be of interest for the impact assessment of shellfish culture. Various diversity indices are classical in describing the ecological diversity among communities (Shannon-Wiener index, Margalef index, species richness, Pielou'Evenness, Abundance and biomass, Number of species, A/S, B/A). Sometimes, they can fail in revealing the structure of communities submitted to heavy organic load from mussels farms (Grant et al., 1995). However these indices may still be used in many cases to characterize the impact of shellfish aquaculture.

Some diversity indicators have been proposed to describe the change in biodiversity occurring under the shellfish culture, and are under test, notably within the course of the ECASA project:

- Macrofauna multivariate indicators intend to classify the different species according to their contribution as revealed by a canonical correspondence analysis,
- The meiofauna diversity indicator is under test by the research teams involved in ECASA.
- A size-related indicator has been proposed. It relies on the fact that most of the species tolerant to an organic enrichment belong to families such as the Spionidae, and have a small size. Therefore a differential sieving of the sediment sampled for macrofauna studies, on 1 mm and 0.5 mm sieves, would allow quantification of the relative part of the smaller individuals into the whole community.
- Indicators based on the relative proportion of ecological groups among a community have also been proposed. The AMBI indicator has been tested in various environments and polluted sites. While it is not specific to aquaculture impact, it proved to react properly in the presence of organic enrichment in a manner very similar to those resulting from shellfish culture in confined areas.
- Indicator species or bioindicators are useful in heavily impacted communities. *Capitella capitata* is an opportunistic species that dominates or replaces the other benthic species in the presence of high levels of organic matter, and is distributed almost worldwide. Other species less tolerant to the organic enrichment, can also be found in enriched areas, but they may not have the same wide distribution.

Therefore, a dominant population of *Capitella capitata* may be considered as a good indicator of strong impact of shellfish culture due to heavy loads of organic matter on the sediment.

- Trophic indices are related to the consequences of the organic enrichment into the sediment. It is generally observed that this would favour deposit feeders and scavengers, at the expense of filter feeders. The infaunal trophic index ITI, and the definition of benthic trophic groups have been selected by the ECASA group to be representative of the impact caused by shellfish aquaculture on the trophic characteristics of the macrofauna.
- Sensitive habitats, or sensitive and endangered species (mammals, birds, endangered species) as identified in European union directives and national rules, should be protected from the impact of aquaculture facilities. Shellfish culture does not potentially harm the migratory birds, as long as their feeding territories and their nesting areas are far enough from the human presence. Practically, this results in the exclusion of shellfish culture from these areas, and the presence of these sensitive habitats and species constitutes an indicator of the impact of shellfish culture.
- The use of video monitoring of the sea bed under and at the vicinity of aquaculture facilities also allows indicators to be calculated using image processing and statistical analysis. An example of this is given by Bugden (1998), where the bacterial mats produced in anoxic surface sediments can be tracked by video analysis.

4.2.5.2 Impacts on pelagic population dynamics, community structures and nutrients dynamics

Shellfish aquaculture, under some conditions (largely related to hydrodynamics and shellfish stocking density), has been shown to alter many biological and chemical properties of the water column that control ecosystem structure and function. Owing to the movement of the water, these effects can be transported far-field, with a measurable impact at the coastal ecosystem scale (Cranford et al., 2006, Gibbs, 2007). Several pelagic indicators have been proposed to describe the change in biodiversity occurring under the shellfish culture:

- Rapid synoptic surveys of the *phytoplankton biomass (chlorophyll a) depletion* footprint, resulting from bivalve grazing, reveal phytoplankton depletion at the farm to bay scale (Cranford et al. 2006, Gibbs, 2007 and references cited therein). This pelagic status indicator is also relevant to bivalve induced depletion of, and competition with, the zooplankton.
- *Shift in plankton size spectrum*: A potential consequence of size-selective food particle depletion by cultured shellfish is a significant change in the size structure of the microbial plankton community from larger phytoplankton to smaller picophytoplankton. Given the potential ecosystem consequences of a shift in the pelagic foodweb, indicators of size spectrum changes (e.g. increased picoplankton abundance and proportion of phytoplankton; increased bacteria counts) are perceived as being highly beneficial for use in monitoring programs in extensively leased shellfish aquaculture inlets Cranford et al., 2006). This recommendation was also related to the relatively low cost of analysis, the ease of data interpretation, and the fact that site-specific measurements of plankton community alterations generally reflect conditions over much larger scales of impact.
- A greater *abundance of bacteria* can occur due to consumption by shellfish of some fraction of the natural planktonic grazer community.
- *Nutrients concentrations*: There is ample evidence to link shellfish aquaculture to coastal nutrient dynamics. However, the use of nutrients as indicators of bivalve culture impacts is challenging owing to the high natural short- to long-term variability in nutrient concentrations in coastal systems. Other pelagic indicators (e.g. phytoplankton abundance and productivity and shellfish growth) may act as suitable proxies for detecting impacts on nutrient dynamics

- *Dissolved oxygen (DO)* measurements are relevant to a wide range of aquaculture/ecosystem interactions and are therefore potential indicators of ecosystem status.
- *Shellfish performance indicators* (growth, condition index, etc.), similar to bulk particle depletion measurements, do not reveal information on specific changes in the structure and functioning of ecosystems, but provide an indication as to whether shellfish aquaculture is affecting the system to a greater extent than can be absorbed by natural processes. Particle depletion and shellfish performance measurements are highly complementary, as the former provides information on food supplies that likely control the latter. A major strength is that standardized shellfish performance measures are relatively inexpensive to perform. However, if there is large spatial and temporal variability in environmental conditions (particulate food supplies) in the farmed region, the performance of the shellfish will be site specific. Although the use of caged bivalves as indicators of ecological performance has potential, the interpretation of the results requires complementary information on a wide range of variables that can affect bivalve growth (temperature, currents, food abundance and nutritional quality, salinity, etc.), thereby decreasing the practicality of this approach (i.e. difficult interpretation).
- *Time series of farm stocking and production* have proven useful as indicators of growth conditions within extensively leased mussel aquaculture inlets (Cranford et al., 2006). Long-term trends in total shellfish production (e.g. average mussel and oyster yield per culture unit) have been used to assess the effects of increasing stocking density on bay-wide aquaculture production (Héral, Bacher et al. 1989). These data are generally collected for aquaculture operations and are critical for facilitating the interpretation other indicator results (e.g. phytoplankton depletion, benthic indicators), and as a general indicator for assessing bay-scale ecological performance/status.

4.3 Modelling approaches and applications

Modelling is often used as a tool to predict probable changes in environmental indicators/parameters. Broadly speaking the models are grouped into numerical or quantitative models and qualitative models. The use of a set of monitored parameters, allows prediction of what will happen with a particular indicator under a certain scenario at a given location (qualitative modelling). For example, variation in chlorophyll, nitrogen and light due to shellfish culture in an area can suggest changes likely to occur in primary productivity in a particular water body. Generally numerical models are used to describe our understanding of environmental processes at work at the farm (e.g. near-field models such as DEPOMOD (Cromey, Nickell et al. 2002) that simulates the trajectory of particles from farm sites to assess the degree and extent of particulate sedimentation and associated changes in the benthos.) to the regional scale (e.g. lower-trophic box models). In general, these are prognostic and able to synthesize information and develop scenarios of potential effects that can be transferred to other areas.

Quantitative modelling requires considerably more data than qualitative modelling and is time consuming and expensive to implement and maintain. Complex numerical hydrodynamic-NPZD (nutrient, phytoplankton, zooplankton, detritus) carrying capacity models have been utilized primarily for the "effects assessment" stage within the overall aquaculture management framework (Fig. 2; e.g. Canada and France). From a larger scale ecosystem perspective, other sets of parameters and qualitative modelling may be a more cost-effective and pragmatic approach. They allow incorporation of useful qualitative information supplied by local stakeholders (e.g. shellfish farmer) on their perception of changes in local ecosystem states and functions.

The most effective quantitative models for indicating habitat changes due to intensive bivalve aquaculture are simple, calculating interactions between important processes rather than simulating all interactions within an entire ecosystem (Chamberlain et al., 2006). These approaches include ecosystem energy and nitrogen budgets (Cranford et al., accepted) and numerical water column sustainability performance indicators (Gibbs, 2007), which are referred to as index models by Chamberlain et al. (2006). These approaches predict bay-wide outcomes of waste production and removal under different scenarios of aquaculture production, bivalve culture controls of the phytoplankton, and whether or not production carrying capacity has been reached. The simple index models can provide guidance for management considerations, but they assume that everything is spread throughout the bay simultaneously, limiting their ability to describe local inputs and effects.

Fuzzy logic approaches (such as applied by SIMCOASTTM) are capable of combining qualitative and quantitative modelling approaches and their respective sets of indicators. This supports the management of shellfish aquaculture under conditions of uncertainty. All the modeling approaches are constantly and rapidly evolving. They are useful to identify indicators of ecosystem status and associated operational management thresholds, and therefore aid in the development of the decision-making process among regulators, developers and stakeholders (DFO, 2006). Such landscape scenarios via modelling explore whether recent changes in an ecosystem are within the normal range of variability of these areas. These provide a form directly relevant to the development of thresholds of concern used in ecosystem management.

4.4 Thresholds

"Threshold" is a general term of value which can be determined by administrative or scientific processes. For example, there are thresholds such as "no change in water colour due to eutrophication". That is a threshold derived from policy implementation of a sense of what is socially acceptable. The scientific expression might be "no more or less than 1 g l-1 of chlorophyll". The threshold in this case is set by a policy statement. In contrast, if the desire is to prevent mortality of clams you might set the threshold for 6 m g l-1. That is a threshold defined by our scientific knowledge of the organisms' response to environmental change. There are other less well-defined thresholds which determine the point at which ecosystems show a sudden quantum shift from one state to another. For example, a trophic web based on microalgae is a highly productive system for bivalve culture, however, if that system suddenly shifted to a system based on pico-phytoplankton it may have the same or more primary productivity but much of it would not be available to bivalves. In identifying a threshold it is important to be clear on whether the threshold is one determined by policy decisions or by changes in ecosystems.

It is difficult to set a threshold and sometimes the criterion is simply a "no net loss" or "no change". Unfortunately, nature is not static. The environment is always changing. To set an adequate threshold, scientists, managers and all stakeholders must together identify the value of acceptable change from reference conditions. To address these difficulties, ecosystem managers increasingly use a monitoring endpoint, known as thresholds of potential concern (TPC), to decide when management intervention is needed (Biggs & Rogers, 2003). TPCs are a set of operational goals along a continuum of change in selected environmental indicators (Gillson & Duffin, 2007). TPCs are being continually adjusted in response to the emergence of new ecological information or changing management goals. They provide a conceptual tool that enables ecosystem managers to apply variability concepts in their management plans, by distinguishing normal "background" variability from unpredicted change or degradation (Gillson & Duffin, 2007).

The use of thresholds is often based on mean values but it has been shown in many studies that the ecosystem's response to a disturbance is an increase in variability. It is possible to observe no change in the mean values of the indices, although the variability may increase through time, making it impossible to adequately select a threshold. However, setting thresholds based on means are often not enough. It is often the extremes that shift ecological status.

The following is an example of how extreme conditions can have important ecological and aquaculture implications. The cockle (*Cerastoderma edule* L.) is the dominant species at the mouth of the Ulla river, located in the Ría de Arousa of Spain. Normally salinity conditions in the area support a thriving population of cockles (more than 500Tm extracted worth approximately 2 million € per year). However, a prohibition of sand extraction from the river bed in recent years, together with tidal currents, dam controlled flow discharges in the river and strong winter winds has created new intertidal sand banks. These sand banks modify the mixing of fresh and sea waters in the area. Occasionally, this new configuration of sand banks leads to a reduction of salinity in cockle beds (below 10 ppm) for period of 24 h or more. That reduction in salinity results in the death of an important part of the cockle stock. So, while on average the conditions in Ulla River mouth would normally favour cockle growth the occasional dip in salinities make the area no longer suitable for cockle rearing.

In the case of large areas of shellfish cultivation it is not always possible to set thresholds as there is considerable spatial variability in the natural spatial distribution of water quality parameters. Consequently when thresholds are set it is important to determine the sampling design criteria that must be used to determine if a threshold has been passed. Some examples of considerations in deriving the design of sampling methodologies include:

- geographic and topographic location (e.g. Rias, Fjords, Wadden Sea),
- the intensity of culture relative to the area and/or volume of the embayment,
- the time (annually) of spawning events or the appearance of algal blooms (e.g. mussel spawning event Spain: March; the Netherlands/Germany: May; unpredictable appearance of algal blooms),
- the rate of depletion of phytoplankton within bays, estuaries or the open ocean (e.g. exchange/mixing of water body is different; influx from tidal backwaters or other productive areas [North Sea, Rias]),
- the rate of deposition of faeces in high energy environments or water bodies with low currents (e.g. Fjords ↔ open ocean)
- the rate of oxygen depletion within the water column (e.g. low mixing of water and high production of organic matter → raft culture)

There is a need to consider how regional and operational differences impact the applicability of indices and thresholds for assessing shellfish aquaculture ecological effects. Any recommended framework of methodologies and approaches for assessing shellfish aquaculture impacts must incorporates sufficient flexibility to be of use over a wide range of culture species, husbandry practices, and environmental settings, and that is applicable to small to large shellfish aquaculture operations (Cranford et al., 2006). Given the highly diverse nature of the shellfish aquaculture industry, it is not sufficient to simply provide a toolbox of potential indicators and thresholds; it is equally important to make recommendations, based on sound science, as to which tools are most appropriate under different conditions.

In some instances it may be possible to manage small scale environmental conditions by managing aquaculture. However, as the scale of the area to be managed increases, so many other users and factors have to be considered that managing aquaculture alone is inadequate for managing environmental quality. In areas that are traditionally used for shellfish culture and which have at the same time a high annual production output could have an impact on the surrounding ecosystem. Under these conditions, the definition of thresholds for this area makes sense in terms of ecosystem protection or risk management.

There are a large number of different husbandry approaches to shellfish culture. The type of culture will differ in aspects of their interactions with the environment. For example, intertidal culture constantly modifies the natural community on the beach, while longline culture seldom directly affects beach communities. It is therefore often useful to start the search for threshold parameters or indices by considering the type of shellfish culture to be undertaken. Other types of culture techniques include raft, rack (poche), and pole (bouchot) culture.

A possible solution for managing shellfish aquaculture may be the use of qualitative categories for potential environmental change based on the principle that increased environmental risk requires an increase in monitoring effort. The degree of risk may be linked to a list of pre-identified indicators, with the different classes of indicators triggered based on:

- the nature of the operation (e.g. species, culture method and stocking density per area or volume);
- the perceived environmental risk (e.g. EIA and model-based predictions);
- the ongoing measurement of environmental indicators towards verification of operational thresholds; and
- other environmental sensitivity indices (e.g. habitat sensitivity designations).

The inability to adequately define quantitative operational thresholds for some highly relevant indicators of ecosystem performance/status (particularly those describing the structure and dynamics of the water column), owing to present gaps in our knowledge of ecosystems, should not preclude their potential use. The monitoring of relevant indicators is desirable under conditions where environmental impact assessments and ongoing monitoring data indicate a relatively high risk of bay-scale impacts. Of particular concern are potential impacts on suspended particle concentrations and distribution and resulting alterations in pelagic microflora and fauna communities and the pelagic food web. Monitoring of a suite of ecosystem traits that are thought to affect community structure and functional performance (i.e. contextual indicators), is warranted when and where significant water column interactions with the farm (e.g. significant particle depletion) is predicted (see Section 4.3). Surveillance of pelagic indicators would compliment benthic operational monitoring and would support the basic monitoring principle of delineating cause-effect relationships.

4.5 Integrated Coastal Zone Management (ICZM) and Shellfish Aquaculture

In coastal and offshore regions of the EU, human activities are increasing in type and intensity. Larger portions of the sea are sectioned off, dedicated for specific, often exclusive uses that cause rising conflicts between interests groups. As a case in point, site-selection criteria for shellfish aquaculture firstly aim at biological and physical issues whereas social and economic aspects are treated marginal. As a result many well-intentioned efforts towards informing the public on shellfish cultivation have failed because they were looked at in isolation. Site selection and spatial scarcity in aquaculture is thus not solely a technical definition problem but also depends on the social context it operates. ICZM can been seen as tool to overcome this conflict prone situation in aquaculture activities, as one of its key principles is to view problems faced by coastal zones in a wide context, thus to see and acknowledge the 'big picture' of coastal activities. ICZM can be regarded as a strategy for an integrated approach to planning and management in the coastal zone, providing management instruments that are not per se included or foreseen in the different policies and directives in such comprehensiveness (see reports from WGICZM).

The EU ICZM Recommendation (2002/413/EC) defined several items that are relevant to shellfish aquaculture and, at the same time, contribute to the ongoing strategic debate in ICES. In the EU, ICZM is foreseen to employ a strategic approach to planning, in which an ecosystem approach for sustainable coastal development is crucial (EC, 1999). Eight principles of good ICZM practice have been identified, which are the (1) holistic thematic and geographic perspective, (2) long-term perspective, (3) adaptive management, (4) local-context specific, (5) respect and work with natural processes, (6) participation, (7) cross-sectoral approach, and (8) balanced combination of instruments in planning and management (EC, 2002). All of which link to a stronger or lesser degree to shellfish culture operations. In addition, the EU asks for a specific type of reporting process, including improved coordination with bordering countries and acting within regional seas approach as marine resources transcends boundaries.

This ICZM policy framework can be used as a vehicle to recognise, address, and minimise conflicts pertaining to aquaculture operations in a timely fashion before misunderstandings become obstacles. Furthermore, scope for added-value of ICZM for shellfish cultivation in the context of relevant existing and evolving Community policies/legislation exist. In the following a selection of relevant legal and policy frameworks are listed, which have a potential effect on shellfish aquaculture operations in Europe. The summary presented here is based on

4.5.1 Selection of relevant legal frameworks on the EU level

4.5.1.1 The planned Marine Strategy Directive (MSD)

The MSD constitutes the environmental pillar of the future Maritime Policy of the EU (EC, 2005a). It aims to protect and restore Europe's oceans and seas and ensure that human activities are carried out in a sustainable manner. Key elements of the strategy are:

1) a dual EU/regional seas approach for fundamentals in the cooperation of Member States and third countries,

2) a knowledge based approach for decision making,

3) an ecosystem based approach for an integrative management, and

4) a cooperative approach to involve all stakeholders.

The MSD will establish European marine regions and identify potential sub-regions as management units for implementation, on the basis of hydrological, oceanographic, and biogeographic features. The Marine Strategy is consistent with the Water Framework Directive from 2000.

Implications for shellfish aquaculture: The MSD Directive can give guidance and set standards at national and regional levels. The marine regions and sub-regions established by this Directive will provide a good spatial framework in which ICZM can unfolds its strengths to endorse aquaculture operations. However, suitable mechanisms to exchange information and coordinate programs at the coast/sea interface still need to be created.

URL: http://ec.europa.eu/environment/water/marine/dir_505_en.pdf

and http://ec.europa.eu/environment/water/marine.htm

4.5.1.2 Strategic Environmental Assessment (SEA) Directive

The purpose of the SEA-Directive is to ensure that environmental consequences of certain *plans and programmes* are identified and assessed during their preparation and before their adoption. The public and environmental authorities can give their opinion and all results are integrated and taken into account in the course of the planning procedure. In the case of likely significant transboundary effects the affected Member State and its public are informed and have the possibility to make comments which are also integrated into the national decision making process.

Implications for shellfish aquaculture: The role of the Directive is essential for addressing conflicts in the long-term development of coastal zones and for creating synergies of aquaculture activities with other types of uses in the coastal zones, e.g. applying the multi-functional use of space concept. The full potential roots in addressing cumulative impacts of economic sectors such as aquaculture in an ecosystem perspective. The Directive provides a basis for integrated spatial planning and risk management with a view to increasing the sustainability of coastal zones. In this way SEA attempts to act before problems arise, rather anticipating them and adjusting plans to counteract negative consequences.

URL: http://europa.eu.int/eur-lex/pri/en/oj/dat/2001/l_197/l_19720010721en00300037.pdf

4.5.1.3 Environmental Impact Assessment (EIA) Directive

The EIA procedure ensures that environmental consequences of *projects* are identified and assessed before authorisation is given to a project or an investment (EC, 1985; 1997). The public can give its opinion and all results are taken into account in the authorisation procedure of the project. One measure in the EIA process is the strengthening of the ecological component and the possibility to define ecological compensation measures. The results of the EIA procedure have to be taken into consideration in the development consent procedure.

Implications for shellfish aquaculture: In case of aquaculture operations EIA is an essential prerequisite of a participatory approach and a crucial instrument for sustainable development. In addition, ICZM may place aquaculture projects considered under the EIA Directive into a wider coastal planning and management context.

URL: http://ec.europa.eu/environment/eia/full-legal-text/9711.htm

and http://ec.europa.eu/environment/eia/full-legal-text/85337.htm

and http://ec.europa.eu/environment/eia/eia-legalcontext.htm

4.5.1.4 Industrial Installations and the Integrated Pollution Prevention and Control Directive (IPPC)

The IPPC Directive is about minimising pollution from various industrial sources throughout the European Union (EC, 1996). New installations, and existing installations which are subject to "substantial changes", have been required to meet the requirements of the IPPC Directive since 30 October 1999. The IPPC Directive is based on several principles, namely (1) an integrated approach, (2) best available techniques, (3) flexibility, and (4) public participation.

In European Pollutant Emission Register (EPER), emission data reported by Member States are made accessible in a public register, which is intended to provide environmental information on major industrial activities. EPER will be replaced by the European Pollutant Release and Transfer Register (E-PRTR) from 2007 reporting period onwards.

Implications for shellfish aquaculture: The IPPC Directive has the potential to simultaneously *affect* and *protect* aquaculture and fishery even beyond coastal waters. Large industrial installations have become more frequent along the coast. These installations are attracted by existing logistic opportunities (e.g. oil refineries, port facilities) or particular coastal resources. Shellfish operations are particular sensitive to pollution, which can result from these installations (e.g. (e.g. Council Directive 79/923/EEC of 30 October 1979 on the quality required of shellfish waters as amended by Council Directive 91/692/EEC (further amended by Council Regulation 1882/2003/EC).

URL: http://eurlex.europa.eu/LexUriServ/site/en/consleg/1996/L/01996L0061-20031120-en.pdf

4.5.1.5 Global Monitoring for Environment and Security (GMES) and planned Directive for Spatial Information in the Community (INSPIRE)

GMES is a joint initiative of the European Commission and the European Space Agency designed to establish a European capacity for the provision and use of operational information for Global Monitoring of Environment and Security (EC, 2004a). The GMES represents a concerted effort to bring data and information providers together with users to provide a better security against natural and man-made hazards through improved tools of prediction and crisis management used by civil security entities.

In this context the planned INSPIRE Directive has to be seen (EC, 2004b; 2005b). It is a framework that shall establish a common platform for annotating and sharing geographic data between member states – a spatial data infrastructure. It emphasizes the *environmental* reasons to share data between official agencies in different EC countries.

Implications for shellfish aquaculture: The GMES system and the INSPIRE Directive has a clear connection to aquaculture. They provide valuable data and information which can be used in the development and implementation of aquaculture initiatives. A good example for the cooperation between GMES and ICZM and the relevance for aquaculture is the European *Coastwatch* project. In this project, GMES is used to monitor coastal regions. The main focus is on the influx of landside pollution.

URL: http://www.gmes.info/ ,

and http://www.gmes.info/library/files/1.%20GMES%20Reference%20Documents/COM-2004-065.pdf,

and http://inspire.jrc.it/

4.5.1.6 Summary

Under the auspice of the various legislative frameworks the methods employed such as in projects and investments in shellfish aquaculture are scrutinized by e.g. the Strategic Environmental Assessment (SEA) Directive, the Environmental Impact Assessment Directive, the Industrial Installations and the Integrated Pollution Prevention and Control (IPPC) Directive. These reinforce reconciling long-term with short-term interests and are powerful Directives to counterbalance undesired developments pertaining to shellfish aquaculture. A case in point is the prevention of pollution input in the vicinity of shellfish aquaculture installations. However, a risk for undesired trajectories remains and needs to be monitored. The adequate management of coastal space thus requires long-term regular and harmonised monitoring efforts, such as promoted by the GMES system and the INSPIRE Directive. This directive can be regarded as a promising step towards comparable data and results on a European level. However, relevant parameters (also on economic and social parameters) still need to be identified and included as indicators for shellfish aquaculture. These should be incorporated in the regular monitoring programmes on EU level, in which data collection and exchange should be improved.

4.5.2 Selection of relevant policy frameworks on the EU level

4.5.2.1 The Lisbon Strategy

The ten-year Lisbon Strategy, initiated in 2000, was devised by the EU as a commitment to bring about economic, social and environmental renewal in the EU. Under the strategy, a stronger economy shall drive job creation alongside environmental and social policies that ensure sustainable development and social cohesion.

Several European and Environment Council meetings have called for an annual stocktaking on environmental integration into sectoral policies and a regular environmental policy review (commonly understood as the "Cardiff Process"). In February 2005, the European Commission simplified targets and reporting procedures, which resulted a single national action programme for each country, and one EU growth plan.

Although the Lisbon Strategy is mostly geared to improve European economic development and the labour market situation, it also focuses on environmental aspects. Reasonable development strategies in the field of protecting nature and combining economic and ecological aspects in a productive way are seen as key issues in the implementation of future policies.

Implications for shellfish aquaculture: Through the Lisbon Strategy, the protection of the environment is not approached as a singular issue, but is regarded as part of a coupled approach that also comprises the economic use of the coast. In this respect, aquaculture can be viewed as an option to generate alternative livelihoods in rural peripheral coastal regions in which the local labour market remains more or less dependant on coastal resources.

URL: http://www.euractiv.com/en/agenda2004/lisbon-agenda/article-117510

and http://ue.eu.int/ueDocs/cms_Data/docs/pressData/en/ec/00100-r1.en0.htm (Draft)

4.5.2.2 Governance White Paper

In July 2001, a White Paper on Governance was issued by the Commission of the European Union. This White Paper was adopted with the aim of establishing more democratic forms of governance at all levels - global, European, national, regional and local (EC, 2001).

Implications for shellfish aquaculture: The emergence of awareness about coasts has been a long standing issue far from being linear. Past policies affecting the coastal zone have been predominantly issue oriented (e.g. water quality) and reactive in their nature. Furthermore the governance of coastal and marine areas and their related activities, such as aquaculture, has remained fragmented between countries and thematic areas (e.g. sectors), at national and European levels. Even though the White Paper does not refer explicitly to the field of aquaculture operations, its content is of immediate importance for the effectiveness of these in reinforcing a more transparent mode of decision-making and management along European coasts.

URL: http://eur-lex.europa.eu/LexUriServ/site/en/com/2001/com2001_0428en01.pdf

4.5.2.3 EU Cohesion Policy

The European Union's Cohesion Policy aims to redistribute wealth between richer and poorer regions in Europe in order to arrive at a more balanced economic integration and overall sustainable development. A number of different aspects that are covered by this policy, namely:

1) to achieve synergy effects in spatial planning
2) to address the spatial aspects of sectoral policies through intergovernmental and subregional co-operation structures
3) to provide access to and from central regions as well as from peripheral ones via transportation
4) to include sustainability in economic and spatial planning and as a possible source of synergy effects

The Cohesion Policy also offers opportunities to fund actions to mitigate or adapt to climate change.

Implications for shellfish aquaculture: In most cases, shellfish aquaculture takes place in rural peripheral areas (e.g. western Scotland, Galicia). The Cohesion Policy emphasises investments in infrastructure, particularly in such Convergence regions, and asks the regions to comply with environmental legislation in the fields of water, waste, air and nature. Investments in sustainable energy and transport, as well as eco-innovation with clean technologies are also promoted in particular in remote and underdeveloped areas. The substantial experience gained from the Cohesion Policy for implementing the principles of subsidiarity and partnership is very useful for developing win-win situations in coastal areas, i.e. aquaculture as means of generating alternative livelihood.

URL:
http://ec.europa.eu/regional_policy/sources/docoffic/2007/osc/l_29120061021en00110032.pdf

4.5.2.4 Maritime Green Paper

So far, EU policies on maritime transport, industry, coastal regions, offshore energy, fisheries, marine environment, socio-economic cohesion and other relevant areas have developed separately. Fragmentation may result in conflicting measures, which have negative consequences on the marine environment (e.g. increased pollution, over-fishing, reduction of marine biodiversity) or may impose disproportionate constraints on competing maritime activities.

In March 2005, the European Commission decided to work on a Green Paper, i.e. a policy proposal, for a future EU Maritime Policy. The Green Paper was adopted in June 2006 (EC, 2006c). It constitutes a first step towards the establishment of an all embracing Maritime Policy that aims at developing a thriving maritime economy and the full potential of sea-based activities in an environmentally sustainable manner, whilst following on an ecosystem-based approach. It intends to embrace the whole maritime complex and design an integrated policy for, among others, maritime transport, fishing, aquaculture, oil and gas exploration, use of wind and tidal power, shipbuilding, tourism and marine research.

Implications for shellfish aquaculture: By acknowledging that 80% of the ocean pollution results from land based human activities the Green Paper puts a clear link between marine and terrestrial environment and therefore is highly relevant to aquaculture activities. ICZM will provide the link between the Maritime Policy, the Marine Strategy Directive with the sea on the one hand and the Water Framework Directive (EC, 2000) and other governing instruments of the land side on the other hand. This offers opportunities to promote a continuum of integrated planning (with emphasis on both environmental and socio-economic aspects of planning) and management of aquaculture.

URL: http://ec.europa.eu/maritimeaffairs/pdf/com_2006_0275_en_part2.pdf

and http://ec.europa.eu/maritimeaffairs/

and http://ec.europa.eu/maritimeaffairs/policy_en.html#com

4.5.2.5 Sixth EU Environmental Action Programme

The Environment Action Programme provides a strategic framework for the Commission's environmental policy up to 2012. The programme identifies four environmental areas for priority actions, also considering economic and social aspects:

- Climate Change
- Nature and Biodiversity
- Environment and Health and Quality of Life
- Natural Resources and Waste

The Sixth Environment Action Programme (6th EAP), which was adopted by the European Parliament and Council in 2002 and runs until 2012, requires the European Commission to prepare Thematic Strategies covering seven areas:

- Air Pollution (adopted 21/09/2005)
- Prevention and Recycling of Waste (adopted 21/12/2005)

- Protection and Conservation of the Marine Environment (adopted 24/10/2005)
- Soil
- Sustainable Use of Pesticides
- Sustainable Use of Resources (adopted 21/12/2005)
- Urban Environment (adopted 11/01/2006)

The Thematic Strategies represent the next generation of environmental policy and focus on identifying the most appropriate instruments to deliver European policy goals in the most cost-effective way.

Implications for shellfish aquaculture: The Thematic Strategies developed under the EU Environmental Action Programme are confined to a theme or sector. Several of these have direct links to aquaculture. They provide the opportunity to take up specific themes related to aquaculture operations and to bring its implementation into a wider context: from local, regional to national. It thus serves as an important vehicle to support and back up aquaculture operations.

URL: ec.europa.eu/environment/newprg/index.htm,

and ec.europa.eu/environment/newprg/strategies_en.htm

4.5.2.6 Summary

In various ways, the policy frameworks of the EU influences and supports shellfish aquaculture. Even in cases of very general policy frameworks, such as e.g. the Governance White Paper, important incentives for the shellfish operations exists by e.g. providing an area of engaging coastal societies in more transparent decision-making and co-management of coastal areas. Conflict resolution through informed public debate can be a key to make shellfish aquaculture more acceptable in the broad public. Furthermore, scope for streamlining shellfish aquaculture throughout the EU exists by the link of terrestrial/coastal (as stipulated by the Water Framework Directive) and the planned Marine Strategy Directive (the "Marine Regions"). In both cases, an ecosystems-based management approach is either already in place or planned to be formed. During recent years the EU has made significant progress in devising policies with respect to encouraging the integration of sectors and the involvement of stakeholders and the wider public. As a case in point, the EU Cohesion policy aims to synergize economic and environmental concerns.

4.6 Conclusions and Recommendations:

Shellfish aquaculture operates in a highly complex legal and policy framework in Europe. However, this should not be regarded as been a constraint, but rather an opportunity to seek options for using the framework for shellfish aquaculture. A case in point is the establishment and extension of several EU-wide monitoring programmes that could endorse a set of indicators relevant to shellfish aquaculture.

- The selected parameters used to measure an impact should be characterized to detect how they are likely to respond to change in the case of different situations (size and type of shellfish farming; local versus regional geographic scales…).
- A threshold should be based on a scientific background while at the same time social values should be incorporated when deciding how important a change would be before it is considered unacceptable.
- The WGMASC recommend that ICES work on the definition of categories/classes instead of thresholds if used in large areas.
- The WGMASC proposes to include some of the proposed indicators into these monitoring schemes and to streamline these with the existing programmes on EU level.

- Furthermore, it is recommended to carry out a similar analysis on the relevant legal and policy frameworks and the role of ICZM influencing to a higher or lesser degree shellfish aquaculture activities for the other ICES Member states (e.g. Norway, Canada, Iceland, USA).
- The WGMASC recommends to link stronger with the WGICZM and to include socio-economic perspectives in the analysis of shellfish aquaculture. Whereas the local/regional bio-physiological and physical settings set the stage on which shellfish operations can occur, social and economic properties determine the type and the intensity of the aquaculture activities.
- The ICES advisory activities should support capacity building on the local level e.g. in “convergence areas” (peripheral rural regions off the main transportation routes) of the EU. These may provide a valuable source for capacitating shellfish farmers to be actively involved in a local proactive monitoring programme as proposed by ToR A.

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5 Prepare a report assessing the integration of aquaculture techniques to enhance wild scallop fisheries with the view of improving the management of this resource (ToR c)

5.1 Background

Spat availability is fundamentally important to the shellfish industry, which relies upon both hatchery production, as reviewed by WGMASC (2004 and 2005), and the collection of spatfall from the field. Recent developments in shellfish production in some countries are based on hatchery produced spat. This is the case for scallop production, which is reared in open waters by means of long line culture or bottom culture, and dived or dredged in coastal areas. Stocks depletion in scallop beds, in certain countries, has led to the use of hatchery reared spat for reseeding, in order to sustain the production. This technology was developed where the collection of wild spat was not cost effective, e.g. in the United States and France (Bell et al, 2005). In France, the largest single releases have involved production of five million postlarvae resulting in a harvest of 100 tonnes of live scallops (Dao et al., 1999). Mussels produced by cultivation (hatchery or spat collectors) can also be used in restocking programmes, e.g. via natural settlement in Scotland, Ireland and recently by hatchery production in France and The Netherlands. Fished spat and adults mussels can also be used for aquaculture purposes. Oyster production in some countries still heavily relies on the availability of natural spat settlement, including restoration programmes, even though oyster hatchery technology is at quite an advanced stage of development in many countries. Therefore, a continuum exists for the shellfish production, from fisheries to aquaculture. Management issues relating to integrated production are emerging in ICES countries in relation to awareness of regulation and development of policy, such as the relative costs of leases for aquaculture and taxes on enhancement of fisheries (e.g. Rade de Brest). There is also a general lack of awareness of technological developments and communication between fishermen and aqua culturists at base level. Several aspects need to be specifically addressed, in reference to the ICES Action Plan, and advice provided on the implication of ranching on harvesting wild populations to Science (e.g. MCC, RCM and LRC) and Advisory Committees (e.g. ACME).

The report focuses on the species *Pecten maximus*, however techniques may pertain to other scallop/ molluscan shellfish and reference is made to other species where appropriate.

The WGMASC is tasked to specifically address:

- culture techniques,
- population dynamics parameters, such as growth to commercial size and mortality,
- monitoring during ongrowing stages,
- yields, number and cost of seeded spat vs. fished adults, and
- the potential impacts of culture and dredging should be collected and assessed from different sources.

Two fundamental questions raised by this term of reference are:

1) how can mollusc culture be integrated within the management of wild fisheries to achieve long term sustainability without compromising the marine ecosystem, and

2) what is the future of wild scallop fisheries in relation to scallop farming and stock enhancement, within ICES countries?

5.2 Wild Scallop Fisheries Enhancement

Scallop fisheries worldwide are valuable resources which require monitoring, protection and enhancement to maintain sustainability. Their potential may be enhanced by good fisheries management together with the introduction of aquaculture techniques to rejuvenate and enhance stocks (Bartley and Bell, 2006). Throughout the world there is a growing commitment to the preservation, maintenance and restoration of coastal ecosystems and there is recent evidence worldwide of success in scallop stock enhancement, using combinations of fishery management and aquaculture (Fleury et al., 2003; Marsden and Bull, 2006; Uki, 2006). This term of reference considers current practices and attempts to provide guidance on their application. Consideration is given to the impact of fishing techniques, current methods employed to maintain fishery sustainability and the identification of stocks under pressure. The contribution of aquaculture techniques, namely seed supply, ongrowing and relaying is assessed together with the potential roles of stakeholders. This guidance related to scallops might be applied to other molluscan species, when problems occur.

Important questions have been raised on the roles and future potential of scallop fisheries and aquaculture. Fisheries managers tend to operate independently of the aquaculture industry and the potential benefits of integrating some industry activities may not yet be fully realised. Assessments might be tuned to identify areas that could benefit from a combined programme of stock enhancement and rejuvenation, including cultivation techniques being driven by fishermen in conjunction with the shellfish farmer. This methodology would be designed to improve the long term sustainability of the fisheries, while promoting aquaculture methodologies that minimise the impact on the environment.

The following questions will be addressed in the fulfilment WGMASC tasks related to ToR C:

1) How are scallop stocks currently assessed?
2) What fisheries are heavily fished and under increasing pressure?
3) Can discrete, over fished populations be identified at the large or small scale?
4) What potential steps (e.g. restocking) can be taken to rejuvenate stocks?
5) What role could aquaculture play (e.g. augment fisheries management by focussed restocking & stock enhancement or rely on good management of our wild stocks)?
6) What are the benefits of integrating aquaculture methodologies with wild fisheries?
7) Are there potential problems (concerns) related to enhancement methodologies?
8) Should we consider, in the long term, a major shift in production to culture/ranching rather than fisheries?
9) What management strategies can be considered for different species?
10) Can integrated management strategies be generally applied to all ICES member states

The group looked at the current world role of aquaculture in restocking and stock enhancement of wild stocks, closed areas and their management, and from the evidence has considered possible recommendations for the future.

5.2.1 Current methods of wild stock assessment

Assessment of management areas can involve regular visits to processors to sample the size and age of scallops from different vessels in a fleet. Assessment methods using size and age data as well as landings information are used to study the state of the stocks, trends in fishing mortality, biomass and recruitment and would indicate if restocking is needed. The assessments may also include information from research vessel surveys that use special sampling dredges to obtain catch rate data. These data can be used to provide an index of stock abundance and an indication of the numbers of pre-recruits. The surveys can also provide information on scallop stocks when fishing is closed to commercial vessels and perhaps lead to the identification of areas that are heavily fished and in need of restoration. They can also provide predictive information on the gonadal index of scallops prior to spawning and potential wild spat abundance.

5.2.2 Availability of seed for wild fisheries and in aquaculture

A reliable source of good quality seed is essential for both aquaculture and recruitment to wild fisheries, and may be obtained from; spat fall directly onto the sea bed from the wild, settlement onto artificial collectors, and/or from a hatchery. The advantages and disadvantages of these sources are described in Table 6.

5.2.3 The relative cost of seed production from natural settlement and hatchery

Producing scallop seed from a hatchery has obvious costs, covering spat production and nursery stages, prior to juvenile release to the sea bed where there is limited protection against predation. This is advocated for natural spat reseeding and the enhancement of fishing grounds. However, seed obtained from natural spat settlement also has a cost, which has been identified as € 0,09 per individual for juveniles originating from Scotland or Ireland (Dao et al. , 1992). At the same time, juveniles of the same size (3 cm) were produced in a hatchery at a cost estimated to € 0,10 per individual. Therefore, for the conditions given in that report, the production costs for the two methods of juvenile production (from hatchery/nursery, or from natural spat collection) appear comparable. The cost of cultivation is higher on bottom than in suspension and some species (e.g. *Pecten maximus*) seem to require bottom culture during the growout stage. However costs are dependent on price of seed, survival/recapture rate during growout and socioeconomic considerations. The general development in Japan has been aimed at sea ranching rather than suspended culture, and, on economic grounds, suspended culture was regarded as not viable in New Zealand. A European Union project (Fleury et al 1997) was initiated on the hypothesis and general consideration that seabed culture had greater potential and was more cost effective in Europe than suspended culture. For countries with different socio-economic considerations, such as Chile and China, suspended culture has been the more cost effective method of cultivation.

Price does not seem to be a deterrent against production of seed from hatcheries; however the initial outlay of the facility should be taken into account.

An analysis conducted on the later life stages have shown that the production costs of *Pecten maximus* of a commercial size (10 cm), strongly depends on the final capture rate (Paquotte and Fleury, 1994; Strohmeier and Skjæggestad, 2003). In France profitability may be obtained for a ratio of 30% of final capture, to a selling price of € 3.5-4 per Kg (120 gram average weight per individual at harvest) (Paquotte and Fleury, 1994). Financial models for scallop ranching, based on data from experiments and information provided by the Norwegian industry, demonstrated income from the fifth year of operation onwards and significant economic potential once a company has come into regular production. However building up biomass is an expensive process (Skjæggestad and Magnesen, 2006).

5.2.4 Natural Spat Settlement

Spat are known to settle onto shell, hydroids, bryozoans, polyzoans, angiosperms, unattached on the sea bed on the same ground as adults, and also in inshore waters. Substrate characteristics play an important role in successful settlement (Pacheo, 2003) in *A. purpuratus*, offering feeding and protective benefits. Coralline red algae, maerl, can provide a nursery area for *Pecten maximus* (Fraser, pers. comm..) and is the preferred attachment for queen scallops (Kamenos, 2004).

Natural Pectinid spat settlement is unreliable and difficult to predict (Ito, 1975), however forecasting tools are available in the form of: monitoring of adult gonadal index; plankton surveillance; larval identification; monitoring spat settlement onto artificial collectors, and molecular diagnostic tests for species identification.

Natural pectinid spat settlement is unreliable and difficult to predict (Ito, 1975), however forecasting tools are available in the form of: monitoring of adult gonadal index; plankton surveillance; larval identification; monitoring spat settlement onto artificial collectors, and molecular diagnostic tests for species identification.

Time and intensity of settlement is affected by climatic & environmental factors e.g. water temperature, food availability and perhaps lunar periodicity, which cause temporal and spatial variation in annual settlement (Fraser, 1991).

Table 6. Advantages and disadvantages of obtaining scallop seed supply from hatcheries versus wild spat collection

Consideration	Wild fisheries	Aquaculture from hatchery	General comments
Spat production variability	Variable among years	Production on demand	Fishermen need to have more control on seed availability
Reliability	Variable	High potential but presently unreliable in some countries	To secure an income for stakeholders, a stable reliable supply is essential
Spat quality	Spat quality dependant on environmental cycles	Spat quality can theoretically be managed through the feeding regime	Profitability depends survival rates and on spat quality
Introduction of exotic species	High risk if sourced from different locations	Sensitive if alien broodstock or exotic algae are used in the hatchery	ICES recommendations and EU regulations on the introduction of species should be reinforced
Spatfall prediction	Difficult to predict, tools exist	Spat can be produced and seeded on demand	Need to improve spatfall prediction using tools operational on other species (e.g. gonadal index monitoring, larvae sampling, molecular techniques).
Spat collection	Poor results predicting temporal and spatial availability	N/A	Need for optimising collectors and their use: time of use & immersion to ensure efficient settlement, etc…
Good Sanitation	N/A	Essential to avoid pathogen interaction.	100% mortality can result from the introduction of infections such as irodovirus/vibrio sp.
Diseases	Diseases cannot be controlled	Diseases can be identified and controlled.	Relates also to spat quality
Sensitivity to environmental conditions	Subject to annual environmental conditions	Produced in a more controlled environment	A controlled environment is most desirable when broodstock maturation is required
Predation	On early stages, difficult to control	Controllable	Profitability depends on low predation
Mortality	Subject to high mortality	Control is easier. Production can be adjusted to the demand for seed	
Impact of HABs	Affected by regulations	Possible to control (e.g. quarantine), however also subject to regulation	
Costs	Can be low cost where settlement numbers are high	Expensive to set up.	Actual costs need to be assessed in both cases
Market supply and demand	Traditional product in demand.	More flexibility to seasonal markets. May be less demand when natural settlement is good.	Hatchery offers greater flexibility in timing and location of stocking.

CONSIDERATION	WILD FISHERIES	AQUACULTURE FROM HATCHERY	GENERAL COMMENTS
Regulation	Include minimum landing size to prevent over fishing and measures to prevent disease and environmental issues.	Preventative measures for disease and environmental issues.	Regulations are necessary to protect the resources against over fishing and to ensure a safe and healthy product
Genetic diversity	Potential risk in moving spat between areas.	Careful selection/ significant number of broodstock necessary to avoid inbreeding	

5.2.5 Hatchery Production of Seed

The production of seed from hatcheries offers a more controlled environment for a more reliable, consistent supply of spat. Unsuccessful natural spat collection has been a main driver for development of hatcheries in France and Norway. Wild broodstock is introduced during spawning cycles, e.g. early spring and conditioned to spawn. Methods of improving the efficiency of brood stock conditioning have recently been developed, eliminating the need to consider seasons of year, by manipulating temperature, day length, and feeding regimes of the conditioning process (Bergh and Strand, 2001; Magnesen et al., 2006. Spat are transferred to sea in summer to early autumn at 2-15 mm into culture systems, land based raceways, suspended long lines or directly onto the seabed (Magnesen and Christophersen, 2007). A good quality, pathogen controlled water supply is essential for successful larval and post larval production. Problems have been identified in the early culture of *Pecten maximus*, factors such as sanitation, temperature and inappropriate feeding regimes cause high mortality and affect the consistency of hatchery supply (e.g. in France, Norway and Scotland). The causes of high mortality of larvae and spat, such as bacteria and viruses have been well documented by countries where production is enhanced by the therapeutic use of antibiotics. Recent research has resulted in the development of better hatchery systems, improved biosecurity, which has reduced antibiotic use, minimising environmental impact (Magnesen et al., 2006). Capital investment and trained manpower in practical and technical issues are essential in hatchery development, where good husbandry is a paramount consideration.

5.2.6 Genetic considerations

Information on genetic composition and polymorphism (occurrence or lack of deficits of heterozygotes, gene flow, intraspecific or mixed-hybrid character, taxonomic status) should be known in local populations and stocks under exploitation.

Origin of specimens to be used for brood stock should be carefully chosen to maintain genetic diversity, local physiological traits (as adaptation to local conditions, timing of spawning, size at maturation) and morphological characters. There is a tendency for broodstock to be selected for certain characteristics, including growth rate, meat yield, size, uniformity, survival, temperature tolerance, disease resistance, taste and colour. Care, however should be taken to avoid loss of genetic integrity and to avoid inbreeding, which can have an unforeseen impact on cultivated and wild stocks. Recent personal communications from Europe suggest hatchery reared spat can be thin shelled and subject to predation by crabs and starfish, which may reflect a lack of care in broodstock selection or result from poor hatchery or nursery rearing conditions.

Sufficient numbers of females and male broodstock should be used in crosses to prevent reduction of genetic polymorphism due to founder effect and inbreeding in hatchery production of spat. Brood stock originating from possibly close geographic area or optimally the same local area should be used for restitution and enhancement of natural populations and sea ranching. In Norway, recent legislation on sea ranching stipulates that scallops only be released from locally sourced broodstock (Agnalt et al., 2003). The definition of local broodstock is precautionary owing to insufficient scientific evidence on the spatial relationship between broodstock populations and subsequent recruitment to an area. *It is recommended that further genetic studies on scallop populations be undertaken to determine whether geographic-based genetic population structuring exists, which could influence future wild stock management regulations*. Relocation of spat can contribute to gene flow and introgression of genes from one location (population) to another. Efforts should be undertaken to avoid replacement of some local populations by relocated specimens. Research into effects of relocation on introgression and geographic distribution of traits and stocks should be undertaken to ensure synchrony and spawning success. Recent molecular studies on the identification of mussel and scallop bivalve larvae has resulted in the development of PCR protocols which can be used to differentiate between these genera, but not between species in the genera (based on species tested). Differentiation is based on size differences in the amplification products. Specific primers were used to target the mitochondrial 16S ribosomal DNA gene and the nuclear 18S ribosomal DNA gene. Both protocols have been tested with *Mytilus* spp., *P maximus* and six other bivalve species of other genera, from a wide range of Irish and European locations (Bendezu et al, 2005). Cross reaction of the specific primers with DNA template from any of the six other bivalve species was not observed (Bendezu et al, 2005). Future consideration of triploidy to obtain sterility and increase rate of growth may be considered in hatchery production, currently 100% success rate has not yet been achieved.. This treatment would also limit the impact of introgression to indigenous populations.

Suspended culture and bottom seeding of the sea scallop (*Placopecten megellanicus*) in the Magdalen Islands relies on spat collection from a sector different area. A study of more than 1500 adult individuals, from 18 beds in the Magdalen islands, the Gaspe Peninsula, the Southern Gulf, the Lower North Shore as well as spat and juveniles from the Fond du Sud-Ouest was undertaken to provide basic data on the genetic characteristics of the sea Scallop in the Gulf of St. Lawrence. These data are to be used as a reference point in future studies e.g. to demonstrate the effects of environmental variations on aquaculture. The only genetic differences detected were linked to small populations within relatively closed bays on The Lower North Shore, where larval dispersion was limited (Canadian Aquaculture R&D Review, 2007).

5.2.7 Factors Affecting Scallop Production

5.2.7.1 Predation

During its life cycle, the scallop is subject to predation from various organisms, particularly fish, seastars, crabs, cephalopods and gastropods (Ansell et al., 1991: Bergh and Strand 2003; Fleury et al. 2003; Strand, 2006). Adult scallops (> 50 mm in *Pecten maximus*) have been observed to have an enhanced ability to resist predator attack, whereas juveniles are more prone to predation. In northern Europe predation by the edible crab *Cancer pagurus* has been the main problem facing scallop-ranching (Strand et al., 2004; Fleury et al., 1997, Fraser, 1983). Studies of survival in sea-ranching cultures have shown that cultivated scallops need to be at least 6 – 7 cm in size before survival rates increase (Lake et al., 1987: Grefsrud et al., 2003). Drilling organisms, such as *Natica* sp. or *Ocenebra* sp. also actively attack spat and juveniles. The level of predation on recruitment may be very high and the success of scallop aquaculture or stocks enhancement relies on its strict control. In Scotland and in Norway, almost 100% mortality from crabs and starfish was observed in spat released directly onto the seabed post settlement (Strand et al. 2004, Howell, pers com), while experience in New Zealand reported 15% survival of spat released for stock enhancement (Bull, 1994). In Australia poor survival of spat via smothering & predation was found from direct release

(Thomson, 1995, Gardener, pers. comm., 2001). It is important to acclimatise seed before release to build up energy reserves.

Exclusion experiments have shown that much better survival rates are obtained for spat protected against predator organisms. Because of its economic value, hatchery reared spat tends to be ongrown in containment in sea lochs to commercial size: the most commonly used equipment being pearl and lantern nets hung from longlines. In Scotland, spat ongrown in clean pearl nets achieved 90% survival at 2 years old (Howell, pers. comm.). Spat survival greater than 70% is considered viable for intermediate culture at sites in Norway having a minimum temperature no lower than 4 C (Strand and Brynjeldsen, 2003). In Japan, spat was released at 30mm on low mud substrate to obtain optimum survival of *Patinopecten yessoensis* (Ventila, 1982). Seabed fence systems have been developed in Norway which prevent predators, such as crabs, from gaining access to seeded scallop spat (Strand et al. 2004). Results have shown that an effective fence enables the farmer to achieve an 80% survival rate depositing spat greater than 30-50 millimetres in length. The system reduces, indeed near eliminates the costly suspended-culture phase, enhancing potential profit. The hatchery production of spat early in the season enables their release to the seabed in their first autumn (at 30 millimetres length). Attempts to coral or fence small areas of the seabed in Scotland have resulted in their destruction, or removal of stock within them (by fishermen – operating dredge and diver). This is despite full consultation with relevant authority, fishermen and their representatives (Fraser, pers. comm.).

In Canada in the early 1990's, considerable effort was expended in Quebec, Nova Scotia and Newfoundland to develop an aquaculture industry for *P. magellanicus*. These efforts have largely failed, for various reasons including unreliable supply of natural and/or hatchery spat and poor economic viability. The latter was largely driven by industry reliance on production of 'meats' i.e. the adductor muscle which is the only scallop product offered for sale in the North American marketplace. A number of financial models were produced which generally showed poor economic prospects for an industry relying on 'meat' production. Logically, this should have pointed the way towards market diversification into other product forms, possibly the sale of whole scallops in the shell at smaller sizes (Penney and Mills, 2000). Such a product could potentially be marketed to compete with similar product forms of other bivalve species such as clams. It is considered that such products have been marketed in certain European countries. However, no concerted effort was made in Canada by government or industry to promote such products or develop markets. This highlights the need for market research on product diversification, included value added products to enhance aquaculture and subsequent product development.

It is essential to balance the cost of ongrowing in containment against a direct release of post settlement spat to the seabed. Labour and equipment induce extra costs that have been found to be comparable with the cost of natural spat collection (e.g. Dao, 1992). When ongrown on the sea bed, bottom grown adult scallops survive well unless damaged by dredge (Fraser, 1983) and do not move large distances when relocated (Howell & Fraser, 1984). Therefore survival from the juvenile stage to harvest is expected to be high, dependant on size of deposit and level of protection to animals.

5.2.7.2 Environmental impacts

Both aquaculture and wild fisheries for scallops may produce an environmental impact on the marine environment (Jenkins et al. 2001), mainly affecting the sea bed (reviewed in: WGMASC, 2004; 2005) and Cranford et al. 2003). Scallops filter water in the process of respiration and feeding on suspended matter. The result of filtration is that particles are expelled as faeces and pseudofaeces, which are rich in organic matter. These particles rapidly settle to the seabed, and contribute to siltation and organic enrichment. Scallop beds and fishing activity on them also contribute to changes in the composition and abundance of benthic communities. Available bivalve bioenergetic models are able to predict rates of mussel egestion (e.g. Grant et al., 2005). Mathematical models (DEPOMOD, TRIMODENA) allow prediction of sedimentation from suspended culture; however they have limited use in the case of animals living on the sediment surface.

Impacts of the wild fishery appear to be related to the mode of fishing, e.g. via scallop dredging. These devices contribute to modify the surface structure of the sediment down to 10 to 20 cm, and to drastically perturb the epifauna and endofauna, including burrowing organisms such as bivalves, polychaetes and demersal fish. The environmental impact of scallop dredging could influence both the productivity of beds and their ability to sustain recruitment to them. These are important considerations for settlement and survival of seed settling directly onto the sea bed, which is closely linked to restocking activities. If the substratum is significantly altered it may negatively impact on the preferred location for adults and attachment preference for settling recruits. Such an impact is difficult to prevent in deep water fisheries, however, measures may be introduced to limit the impact through good fishery management e.g. closed areas and reseeding spat onto protected areas. Scallops in shallow waters can be collected by divers and seabed impact from such harvest is deemed very low/non existing, except where scallops below the minimum landing size are taken, preventing them from spawning to that area. Considerations on the sediment size, the presence of rocks and the nature of the benthic communities should be carefully addressed, in order to minimize future impacts of fishing and prevent irrevocable damage to the sea bed.

The introduction and transmission of pests and disease is an environmental risk associated with aquaculture where movements of broodstock and spat are routinely made. Test certification of broodstock and screening of spat prior to redeposit are essential elements of farm site biosecurity to minimise the risk of introduction of disease and hitch hiker species, some of which can be non-indigenous to the area of destination. For example, Scottish National Heritage are currently very concerned about the spread of *Sargassum muticum* within Scottish waters. It was thought to have been introduced unintentionally with commercial introductions of oysters from the Canadian state of British Columbia or Japan to France. Its spread from northern France, including the United Kingdom is presumed to have occurred by natural means (http://www.jncc.gov.uk/page-1677). It is common practice when transporting oysters to surround them in sea weed in an attempt to keep them cool and enhance respiration. Care should be taken to prevent the introduction of *Sargassum muticum* with such movements.

5.2.7.3 Harmful algal blooms

Shellfish toxins such as paralytic and diarrhetic shellfish poisons (PSPs and DSPs) occur regularly in bivalves harvested areas, e.g. from Scottish waters with both groups responsible for periodic harvesting bans on human health ground - demoic acid being responsible for closures in the majority of Scottish scallop fisheries in 1999 (Gallacher et al., 2000). Amnesic shellfish poison (ASP) was present in 2005 in the Bay of Brest. Although the main effect of harmful algal blooms is to human health, they can be the cause of mortalities among fishes and invertebrates, including smothering of stocks as the bloom sinks to the sea bed (Chauvaud et al., 1998). Scallop species are also considered sensitive to species that produce toxins.

The main difference in risk between hatchery produced seed and spat obtained from natural settlement is the sanitary measures that are currently in use within the hatcheries, together with the enforcement of dedicated monitoring programmes that can reduce the risk of mortalities for scallops maintained in a hatchery or an inshore controlled nursery. Early scallop stages originating from the two sources are equally at risk when on grown in the open sea. Scallops have been shown to have relatively long depuration times for algal toxins, which could be an important factor in area selection for re-stocking and/or aquaculture activities since long or frequent regulatory closures to harvesting would have a significant negative impact on economic viability of enhanced/ranching or aquaculture operations located in such areas.

5.2.7.4 Regulations

Two types of regulations should be considered, those having a general impact on shellfish culture or fisheries, and those that are enforced for the specific management of scallop resources. Among the former are European directives, such as the Shellfish Directive 91/492/EEC, the EC Directive on Shellfish Growing Waters 79/923/EEC, the Habitats 92/43/EEC, Wild Birds Directive 79/409/ECC, and EC Fish Health Directives 91/67EEC & 95/70EEC (currently under revision). These directives do not affect the supply of seed from hatcheries or from natural spat settlement, except where habitats are protected or when reseeding from non approved or protected areas - as defined in the directives. Directives under the EC are interpreted and implemented by regulations within EU member countries, e.g. UK Fish Health Regulations, 1997 enables controls under EC Directive 91/67EEC to be introduced for serious diseases of shellfish. Further examples of legislation and its interpretation in Spain include:

1) *Regulation on the water quality control for shellfish farming*: Directive of the European Council 79/923/CEE (30th October) → applied in Spain Law through the Real Decreto 38/1989 (Boletín Oficial del Estado nº 17, 20th January).
2) *Regulation on technical and sanitary control of commercial shellfish and rules on production*: Directive of the European Council 91/492/CEE (15th July) → applied in Spain Law through the Real Decreto 308/1993 (26th February) and Real Decreto 345/1993 (5th March), both in (Boletín Oficial del Estado nº 74, 27th March).
3) *Technical and sanitary regulation which fixes the rules for shellfish production and sale (MODIFICATION)*: Directive of the European Council 97/61/CEE which partially modifies the Directive of the European Council 91/492/CEE (15th July) → applied in Spain Law through the Real Decreto 571/1999 (9th April) which gathers all the decrees included in the Directives cited above.

Spanish Law concerning marine aquaculture permits and licenses:

1) *Raft licenses and concession transference:* Article 59, Law 6/1993 (11th May) (Diario Oficial de Galicia, nº 101) and Article 10 of the Decree 406/1996 (7th November) (Diario Oficial de Galicia, nº 228).
2) *License transference of aquaculture farms in marine and terrestrial areas*: Article 56, Law 6/1993 (11th May) (Diario Oficial de Galicia, nº 101).
3) *Working permits and transference for developing activities in the marine and terrestrial areas*: Article 66, Law 6/1993 (Diario Oficial de Galicia, nº 142) and Article 4 of the Decree 193/1997 (Diario Oficial de Galicia, nº 142).

A discontinuity currently exists in France between the regulation of fisheries (free access to space) and shellfish aquaculture (semi-appropriation of leased space with annual tax). Aquaculture lease fees adapted for the intensive culture of mussels and oysters, have been reported to be excessive for the extensive culture of scallops. Regulations under The Sea Fisheries (Shellfish) Act 1967 are operational in Scotland to establish, protect and improve shellfish fisheres as Several Order Fisheries (see 1.4.1 closed areas). The minimum landing size for scallops is currently standardised at 100 mm in Scottish waters, under EC legislation (Council Regulation 850/98 Annex XII).

In Norway, the fishery for scallops (*P. maximus*) is not regulated, while selling is regulated through licensed dealers. Sea ranching is regulated under the Aquaculture Act and is a framework to support the development of scallop sea ranching in Norway (Leikvoll, 2006)

Management regulations may be very specific for scallop resources at a local level: to protect stocks from over fishing; setting a minimum landing size; defining areas and periods of authorized fishing; removal of predators; promotion of rotational dredging on leases; setting a minimum mesh for dredges; and introducing marine protected areas on which natural broodstock can reproduce ensuring improved recruitment to stocks. These regulations are often enforced by local authorities, however, the approval of stakeholders may be sought to ensure an observance of the rules. Avoidance of illegal fishing is essential for success in reseeding from hatchery-reared spat, as large investments are made to produce and to growth these animals.

5.3 Aquaculture and Fisheries Management

The section was briefly discussed by the WGMASC. An overview of the general topics to be addressed below is as follows:

1) Over fishing & stock replenishment
 - 1.1) Establishment of larger spawning biomass
 - 1.2) Increase harvest potential over long term
 - 1.3) The beneficial effect on adjacent scallop beds
 - 1.4) Restocking – rebuild spawning biomass, by the introduction of juveniles – severely depleted stock
 - 1.5) Stock enhancement – augment, increase productivity of an operational fishery – increase recruitment

2) Management of closed areas and success stories worldwide
 - 2.1) During a 4 year closure in Georges Bank, *P. magellanicus* biomass increased up to 14 times.
 - 2.2) Significant density increases in the Irish sea after the 1989-98 closure
 - 2.3) Observations of changes is population size structure to historical conditions in closed areas

3) Aquaculture to increase sustainable production of marine resources (e.g. improved harvest, optimize stocking densities to maximize yield)
 - 3.1) Ranching in Japan, which began following a decline of scallop stocks in the 1960s, has resulted in a 10 fold increase in production.
 - 3.2) Enhance using hatcheries & farm techniques, then release.

4) Control of predators

5) Rotational fishing to stabilise areas, without enhancement

6) The key role of the fisherman

7) Market expansion with value added product

5.3.1 Overfishing & recruitment failure

There is a tendency to overfish scallop stocks. For example, in Japan during the early 1960's, there was a decline in stocks to unsustainable levels. Similar events occurred in France (Bay of Brest) in 1960's, in New Zealand (1970's), in Barent's Sea (1980's), and in eastern U.S. (1990's). Recruitment failure, primarily due to predation that reduces broodstock biomass, has also been suggested as mechanism which contributes to boom-and-bust cycles of scallops (Cropp 1998, Beukers-Stewart et al. 2003, Minchin 2003). Many scallop fisheries have collapsed shortly after their onset. Examples include *Pecten maximus* of Cardigan Bay (UK) in 1980 (Ansell et al. 1991), *Placopecten magellanicus* of Mahone Bay (Nova Scotia, Canada) and Nantucket (Massachusetts, USA; Sinclair et al. 1985), Barent's Sea (Strand and Vølstad, 1997) and *Aequipecten opercularis* of Spain, after the 1960's (Román 1991). Factors other than predation may contribute to recruitment failure in scallops and other molluscan populations, such as turbidity, siltation, frosts, disease and pollution.

5.3.2 Management

The recent trend in scallop management worldwide is the use of closed areas, whether experimental or functional, in conjunction with traditional tools such as minimum landing size (MLS), seasonal closures, boat or vessel licensing, limited entry, gear regulations, and consideration of total allowable catches (TAC). The need for these tools is recognised through routine stock assessment (ref. 6.2.1) and consultation with fishermen and fishery bodies. Several examples of successful scallop management (i.e., landings remain stable through time) include fisheries in the United Kingdom, Isle of Man, and Iceland; however, within those countries it is possible to identify discrete areas that are in need of replenishment as the result of persistent fishing (recruitment over fishing). To minimise environmental impacts, scrutiny of fishing methods (e.g., diving, dredge) are proposed, as some fishing methods are recognized as having a detrimental effect on the environment. For example, size, number, efficiency of catch, and impact to bottom environments caused by dredges, is a matter of concern in many countries. Research and development is needed to produce efficient and low impact dredges to minimize negative impacts on bottom communities such as maerl beds (Kamenos et al. 2004) which are recognized as important for recruitment to local stocks. There are some diver-based fisheries that may have other management considerations, e.g. where beds can be denuded via non selective harvest, causing issues of local recruitment to beds.

5.3.3 Closed areas

A temporary closure of areas of the sea bed is recognised worldwide as a potentially useful management tool to increase spawning biomass and subsequent production. An example from the U.S. portion of George’s Bank is indicative of this methodology. Scallop (*Placopecten magellanicus*) fishing was banned within three groundfish closures (17,000 km2) for three years to increase yield per recruit and spawning biomass. Biomass of scallops increased 14-fold between 1994 and 1998. In July 1998, total and harvestable scallop biomasses were 9 and 14 times denser, respectively, in closed than in adjacent open areas (Murawski et al. 2000). Results from these reopenings encouraged managers to contemplate a formal ‘area rotation’ scheme for scallops intended to improve yield per recruit.

In the Irish Sea from 1989-2003, a fishery closure for *Pecten maximus* resulted in an increase in density from 0.5 to 3.5 to 20 animals per 100 m2 by 1998 and 2001, respectively (Beukers-Stewart et al. 2003). By 2003, the number of legal-sized animals was found to be 4.85 x greater than in adjacent, open beds. Sixty percent of animals were above 130 mm in shell length. 50% of stock was > 5 yr old (last found in 1937). At an adjacent, open fishery -- Bradda Head < 5% of animals were greater than 5-yr old. Local recruitment to stock occurred in the Irish Sea and is believed to be enhanced by the closure. The Isle of Man government is now considering four rotational closed areas.

In Ría de Arousa, Spain the closure of a depauperated clam bank during one year period (2005-2006) resulted in a density increase of 30% and 23% for the two most abundant species (*Tapes aurea* and *Dosinia exoleta*) respectively. This bank is under rotational exploitation control from 2006, by alternating fishing amongst the 3 zones in which the bank is divided; the management of the bank by a rotational exploitation method has allowed the recovery of recruitment for many of the commercial species within it, and in some cases, an increase in their production (Sánchez-Mata, et al, 2006).

In Scotland, ten areas of the seabed have been restricted from the public right to fish for specific shellfish species, nine commercial operations and one for research and development (Fisheries research Services, 2006). The size of these ‘Several Orders’ range from 6.5 to 97.4 hectares, covering a total area of over 450 hectares, and have all been granted for scallops, although two include native oysters. Several Orders are statutory instruments under The Sea Fisheries (Shellfish) Act 1967, to establish, improve and protect a shellfish fishery (http://www.frs-scotland.gov.uk). These areas operate as registered aquaculture sites, independent of fisheries interests, although each must be left in an improved state at the end of a set period of time. The mechanism of Several Order fisheries is available to fishermen, to help manage areas in need of improvement and protection. They offer a means of regulating and managing areas closed to public fishing.

5.4 Stock replenishment (aquaculture, enhancement, and restocking)

Scallop fisheries can be replenished through enhancement, restocking, ranching, or a combination of the three. Bell et al. (2006) defines:

Stock enhancement: releases are combined with high levels of fishing effort, allowing high yields to be sustained by a combination of natural recruitment (from wild spawners and spawners derived from releases of hatchery-reared animals).

Restocking: release of juveniles is combined with large reductions of fishing effort to help rebuild the natural stocks.

Sea ranching: animals are released for harvest at a large size in "put-and-take" operations (there is no intention of allowing them to augment spawning biomass.

Most countries that conduct stock replenishment use a combination of all of these techniques.

For example, in Japan, ranching of *Patinopecten yessoensis* followed the decline of scallop stocks in the 1960's and has resulted in an increase in production from 40 tons in 1970 to 536,678 tons in 1996 (Bourne 2000). Wild scallop spat (> 10 mm shell height) is collected in polyethylene collector bags followed by an intermediate culture to rear juveniles to larger sizes to increase their survival before bottom seeding occurs. Number of juveniles sold for culture and release was approximately 200 million in 1975 and 2.1 billion in 2002 (Uki 2006). Individuals from fisheries cooperatives remove scallop predators (mainly sea stars) from the bottom prior to seeding, and then release juveniles at densities of approximately 7/m2. Seeding and fishing grounds are partitioned into four areas to increase landings (Masuda 1998). One-year old animals are released into one area each year and scallops are harvested (at an average rate of > 4/m2 and an average weight of 200 g) when they are four years old (Uki 2006). To ensure that newcomers understand production processes, a three-year training course in production and harvesting must be completed in some Hokkaido villages before an individual may begin harvesting (Uki 2006). This system works efficiently, and the Japanese government grants local fisheries cooperatives the rights to manage all aspects of scallop production from seed collection through harvesting (Ventilla 1982, Uki 2006).

After overfishing wild stocks of *Pecten novaezealandiae* in New Zealand, fisheries managers closed the fishery for two years (1981-1982), and then they introduced Japanese techniques to restock the scallop fishery. This resulted in an immediate success in spat collection (ca. 50 million per year), and fishery landings stabilized at around 5,000 tons per year (range = 2,250 – 8,500 tons live weight from 1983-2002) (Marsden and Bull 2006). During the development of spat collecting techniques, fishermen and managers were able to refine methods that actually resulted in higher yields of spat with fewer collectors. In South Island, nine fishing sectors, plus permanent reserves, are employed, each being open to fishing depending on fishing resource status (stock assessments).

During the past two decades, marked declines in natural populations and fishery landings of bay scallops, *Argopecten irradians*, have occurred along the Atlantic and Gulf coast of the United States (Tettlebach et al. 2002). To combat these declines, restoration projects have used a combination of techniques such as wild spat collection (Goldberg et al. 2000), restocking from nearby natural populations (Peterson et al. 1996), and re-seeding using hatchery-reared individuals (Arnold 2001). Efforts demonstrated that both wild and hatchery-reared scallops can be transplanted a short period prior to predicted spawning to enhance broodstock numbers (Tettlebach et al. 2002).

Scallop (*Pecten maximus*) production in France collapsed in the 1960's (Boncoeur et al. 2003). However, in the Bay of Brest, along the north western coast of France, the production of scallops from hatchery and intermediate culture developed after 1982 (Fleury et al. 2003), and has now reached over five millions juveniles annually. The hatchery, located near Brest and operated by fishermen, with public funding and support by scientists, supplies spat and juveniles for the Bay of Brest, Bay of Saint Brieuc and Pertuis Breton. The success of these seedings remains variable but generally recapture rates over 25% occur (Dao et al. 1999). For example, in 1995, cultivated animals contributed one-third to one-half of the total production of the bay (90 t out of 184 t) (Fleury et al. 1997). Currently, 60-70% of the commercial fishery results from sea ranching programs from which 500 tonnes of scallops are landed annually. A licence is necessary to fish within these three regions. An accidental introduction of the slipper limpet, *Crepidula fornicata*, six decades ago threatens the sustainability of the restocking program due to space competition that gradually has decreased harvestable areas (Frésard and Boncoeur 2006).

As a possible method of increasing the production of scallops in their areas, numerous countries are conducting research and development to incorporate similar enhancement strategies. For example, in Norway a commercial hatchery to produce *P. maximus* was developed in 1995 in Bergen (Strand and Parsons 2006). The first bottom plantings resulted in heavy predation, resulting in the development of fences to protect hatchery-reared seed. This method of deterring predators has resulted in high (ca. 90%) survival rates (Strand et al. 2004).

5.5 Stakeholder involvement

It has been reported that stock enhancement works best when fishermen manage essential operations, for example in Japan, by management by fishermen cooperatives (Matsu Bay). On a 17-km length of coast (1982), produced 3,000 tons *Patinopecten yessoensis* from suspended and bottom culture (Ventilla 1982). In New Zealand, areas are licensed to cooperatives, including locals as stakeholders/shareholders. A levy on stakeholders funds all aspects from cultivations, re-seeding, stock assessment, and annual management (Arbuckle 2000). This has resulted in a market expansion of value product.

5.6 Conclusions

There are problems managing wild stocks of scallops world wide with pressures of increased exploitation i.e. over fishing populations on both a large or small scale, which in turn force stricter management controls. Even within well managed fisheries, areas can be identified which are in need enhancement and/or restocking. Innovative management methods are currently being developed and employed worldwide, in tandem with existing legislative measures such as reducing effort, operating a minimum landing size and boat licensing, to address these issues. These methods of; operating and rotating closed areas, and utilising ranching techniques are being successfully combined with aquaculture techniques (utilising spat from wild or hatchery origin) being released as juveniles to augment recruitment and rejuvenate wild stocks. There is evidence for stabilisation/maintenance of recruitment and yields and increases in biomass in certain fisheries. The beneficial affect on recruitment to adjacent scallop beds has also been highlighted as a result of stock enhancement techniques, as seen in Japan with increased recruitment and productivity of fisheries.

Thus, the benefits of integrating aquaculture methodology with wild fisheries can result in sustained increases in the production of harvestable animals. In many countries however, aquaculture and fisheries exist separately with little knowledge of the potential which such integration could provide. The opportunity certainly exists for fishermen cooperatives to combine farming with fishing to enhance beds and stocks under pressure. It is recommended that industry, policy makers and scientists act to assess the benefits of such methodology and facilitate plans for their use. This could operate at a country or perhaps be coordinated at an ICES level, however it must be emphasised that fishermen have a key role in its success.

5.7 Recommendations

- An integration of aquaculture and fisheries management techniques is recommended in order to enhance scallop production.
- It is recommended that industry, policy makers and scientists act to assess the benefits of such methodology and facilitate plans for their use.
- Fishermen should be encouraged to take a key role in the development and application of those plans.
- It is recommended that further genetic studies on scallop populations be undertaken to determine whether geographic-based genetic population structuring exists, which could influence future wild stock management regulations.
- There is a perceived need for market research on product diversification, included value added products, to enhance aquaculture and subsequent product development.

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6 Identify emerging shellfish aquaculture issues and related science advisory needs for maintaining the sustainability of living marine resources and the protection of the marine environment. (ToR d)

The task was to briefly highlight new and/or important issues that may require immediate additional attention by the WGMASC and/or other Expert Groups as opposed to providing a comprehensive analysis. The following issues were identified by the working group in order of priority for future attention and communication:

1) What is the significance to wild and cultured bivalve stocks of intentional bivalve aquaculture transfers between sites/countries?

1.1) What is the risks for disease and parasite transfer and how can they be minimised? What diseases, existing and emerging, should countries be wary of? Which species are carriers and/or susceptible to serious disease? What are the long term implications of introductions, whether disease or non-indigenous species to susceptible species and the ecosystem as a whole?

1.2) What are the potential genetic, physiological and morphological implications of intentional bivalve transfers for wild and indigenous cultured bivalve stocks? Can the movement of shellfish on a large scale have a significant affect on recruitment patterns to established fisheries/beds?

1.3) What species are transported where, what records are kept, and what guidelines are in place in ICES countries related to the transfer of cultured species?

1.4) What scientific tools are available for decision support on transfer issues?

2) There is a need to investigate the presence of climate change effects on shellfish aquaculture distribution and production? What is the evidence for and effect of climate change in ICES and countries world wide?

3) What new technologies are being used to culture shellfish both offshore and on land? What factors drive such technologies and what are their benefits and disadvantages?

3.1) What is the shellfish production potential compared to traditional cultures?

3.2) What species are most suited to such technologies and what are limiting factors for their production?

3.3) What are the environmental implications of utilizing new technologies for culturing shellfish in alternative areas including exposed, high energy, oceanic environments and practicalities such as servicing and harvesting from sites in remote locations?

4) What are the alternative and value-added uses of cultured shellfish? How can alternative uses result in increased production levels, value and benefits in distribution?

The following sections briefly provide background on each issue and identify some related advisory and research needs.

6.1 Significance to wild and cultured bivalve stocks of intentional bivalve aquaculture transfers between sites/countries

Different shellfish species and life stages are transported from hatcheries and field sites to new culture sites, and often cross international boundaries. ICES Member Countries import live organisms from 32 countries and molluscs are among the most important taxa transported (WGITMO, 2006). With any such transfer between sites, there is the potential for introduction of non-indigenous species. The risks of disease transmission and parasite transfer should also be considered. How can the risks be minimised? What diseases, existing and emerging, should countries be wary of? Which species are carriers and/or susceptible to serious disease? What are the long term implications of introductions, whether disease or non-indigenous species to susceptible species and the ecosystem as a whole?

Presently, the Working Group on Introductions and Transfers of Marine Organisms (WGITMO) documents the spread of intentionally imported and/or invasive species introductions via the use of National Reports from many ICES countries. This group also provides indications of unintentional introductions of parasites and disease agents and tracks the spread of species introduced for aquaculture use that have the potential to become invasive. An example of the latter is the Pacific oyster, *Crassostrea gigas*, which continues to spread in the Wadden Sea and has recently been shown to be reproductively active in Norway (Ø. Strand, pers. comm.). The Working Group on Environmental Interactions with Mariculture (WGEIM) is examining the potential importance of bivalve culture in the promotion and transfer of exotic species (i.e. alien or introduced) and the resulting implications for bivalve culture and the environment. The WGEIM is also examining management and mitigation approaches for invasive and nuisance species that have been transferred to aquaculture sites.

In addition to topics identified in Terms of Reference for the WGEIM (ToR f: Do mariculture physical structures provide a pathway for the introduction of exotic species?) and WGITMO (summarize reports on transfer and introduction of marine species; guidelines for rapid response and control options), the transfer of cultured bivalves has potential implications for the introduction of diseases and parasites that can impact wild and cultured stocks and may cause alterations in indigenous species genetic composition, diversity and polymorphism, and changes in regional physiological and morphological traits. The question of whether the movement of shellfish on a large scale can have a significant affect on recruitment patterns to established fisheries/beds also needs addressed. There is a need to study and identify the significance of shellfish relocations on the geographic distribution of marine organisms, indigenous shellfish stock traits and the potential implications for regional shellfish culture operations. The significance to wild shellfish stocks of such transfers requires information on what species are transported where, what records are kept, and what guidelines are in place in ICES countries related to the transfer of cultured species. In addition, scientific tools for decision support on cultured shellfish transfer issues should be developed, reviewed and assessed.

The WGEIM (2006) report recommended to the Mariculture Committee that key representatives from ICES Working Groups dealing with aquatic exotic species, including the WGMASC, should meet to, among other tasks, identify information gaps and recommend specific research goals. We concur with this recommendation and recommend to the MCC that the WGMASC undertake a new ToR in 2008 on this high priority topic. Communication between the WGMASC, WGEIM and WGITMO is needed to facilitate this task and to prevent overlap in related tasks.

6.2 Investigate climate change effects on shellfish aquaculture distribution and production

The issue of climate change and the possible impact of temperature rise and hydrodynamic changes on shellfish aquaculture have received little research effort. However, climate changes will ultimately have a direct impact on which species are suitable for farming in a given region and will indirectly influence other factors that influence aquaculture, such as primary production, microalgal biodiversity, the presence of nuisance species, oxygen levels and the incidence of harmful algal blooms (University of Victoria, 2000). The increased carbon dioxide would cause an acidification of the oceans, which may reduce the shell growth of molluscs (Gazeau et al. 2007). Climate change may also cause sea level rise and alter salinity, weather extremes, storm surges, tidal regimes, waves and coastal erosion, all of which can impact shellfish aquaculture with a largely unknown net positive or negative result. It is believed that climate change will impact shellfish aquaculture, particularly in the intertidal zone, but knowledge is needed to more fully identify the threats and potential opportunities. Such knowledge will allow farmers to adapt to climate change. ICES (e.g. WGMASC) should consider the current scientific evidence for and effect of climate change in ICES countries and world wide. For example, can summer mortalities in *C. gigas* be attributed to climate change in certain European countries or simply be a result of poor broodstock selection?

As a first step to predicting the potential effects (positive or negative) of the effects of climate change on shellfish aquaculture, any available evidence on climate change impacts on cultured species needs to be accumulated and assessed. This includes information related to a recent OSPAR request for ICES "to prepare an assessment of what is known of the changes in the distribution and abundance of marine species in the OSPAR maritime area in relation to changes in hydrodynamics and sea temperature." The WGMASC recommends to the MCC that the WGMASC undertake a new ToR in 2008 to address this high priority topic.

6.3 Driving factors and resulting new technologies for culturing shellfish both offshore and on land?

Competition for aquaculture space in coastal areas, the need for suitable water quality and technological advances in shellfish culture structures has increased interest in the use of some non-traditional culture sites, including the offshore and land-based culture. As expected for any new operation, the question of environmental impacts at offshore sites has received relatively little attention. However, there is a need to assess potential environmental interactions of these operations and to set environmental standards. Directed research is required to predict and detect potential interactions in alternative culture areas, and to develop best management approaches for this expanding industry. Both off-shore and land-based shellfish culture are still in an experimental stage and up-to-date information is needed on production potential and costs to improve comparison with traditional methods in coastal areas. Consideration should also be given as to which species are most suited to these novel technologies, what limiting factors affect their production and practicalities such as servicing and harvesting from sites in remote locations.

6.4 Identify alternative and value added uses of cultured shellfish

Opportunities are available to the shellfish aquaculture industry to expand beyond the traditional role as food suppliers and to produce value added niche products, whether in the presentation of existing products or for new and novel uses. Shellfish are excellent nutritional sources and shellfish extracts have potential pharmaceutical functions (e.g. extraction of Omega-3 polyunsaturated fatty acids; and therapeutic potential for the treatment of inflammation and inflammatory conditions such as rheumatoid arthritis (McPhee et al, 2007)). Utilization of all parts of the animals is also encouraged to reduce wastes and to increase profitability. The culture of Japenese scallop is a good example of waste reduction through the marketing/utilization of the whole animal. Another example is the utilization of the bivalve shell. Shells are used as insulation for housing and as material in road construction. A recent example of a non-traditional use of shellfish culture results from suggestions that bivalve aquaculture may help ameliorate the impacts of nitrogen enrichment in eutrophic coastal waters by removing excess nitrogen in the shellfish harvest (e.g. Rice 2000; 2001). This has led to the proposition that shellfish aquaculture be incorporated in a nutrient trading system as an alternative to nitrogen reduction for improving coastal water quality (Lindahl et al. 2005). The diversified production, including shellfish, associated with integrated multi-trophic aquaculture (IMTA) is an effective means of recycling aquaculture wastes and provides a more beneficial use/conversion of introduced food and energy.

Research priorities related to these alternative uses of shellfish culture include;

- potential additional pharmaceutical uses of cultured shellfish,
- quantitative assessments of the value of shellfish culture in nutrient trading ventures (e.g. Cranford et al., in press),
- identification of environmental aspects of IMTA, including carrying capacity, diseases, predator-prey interactions and environmental impacts, and
- impacts of regulations related to utlization of shell (e.g. shell introductions for marine uses).
- Investigations on how can value added product result in increased production levels, value and benefits in distribution.

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Annex 2: Agenda

Tuesday 27 March 2007 *Gully Boardroom*

09:30 Welcome to BIO – Tom Sephton, Director, Ecosystem Research Division (past chair of ICES Mariculture Committee)

09:45 Introductions and update on ICES activities – Peter Cranford

- General discussion of ICES activities and Terms of Reference
- Adoption of agenda

10:30 *Health Break*

11:00 Plenary to develop work plan; identify subgroups, subgroup leaders and rapporteurs

12:30 **Lunch**

13:30 Subgroup sessions (ToR = WGMASC Terms of Reference):

- ToR a: *Stress indicators in shellfish (Hayes Boardroom, 1st Floor)*
- ToR b: *Evaluation framework for shellfish aquaculture impacts (Gully Boardroom, 6th floor)*
- ToR c: *Utility of hatchery reared seed to enhance wild scallop fisheries (Trites Boardroom, 4th floor)*

15:00 *Health Break*

15:15 – 18:00 Continue ToR subgroup sessions

Wednesday 28 March 2007

09:00 Plenary – brief overview of work status

09:45 Presentation by Edward Black (Canada): *Aquaculture focused environmental risk assessment work in ICES and GESAMP.*

10:30 *Health Break*

11:00 Presentation by Gesche Krause (Germany): *Integrated coastal zone management status in Europe*

11:30 Reconvene ToR subgroup sessions

12:30 **Lunch**

13:30 Reconvene ToR subgroup sessions

15:00 *Health Break*

15:15 – 18:00 Plenary with overview of ToR a, b and c status by subgroup leaders and discussion on ToR d (*Identify emerging shellfish aquaculture issues and related science advisory needs*)

Thursday 29 March 2007

09:00 Review 1st draft of WGMASC report

10:00 Plenary Session: discussion on draft report

10:30 *Health Break*

11:00 Revision of draft report in subgroups.

13:00 **Lunch**

13:30 Continue revision of report in subgroups.

15:30 *Health Break*

16:00 Plenary Session:

- Review and adoption of the scientific text of the report
- Discussion on Recommendations
- Prepare Executive Summary
- Discussion on new Terms of Reference
- Location of next meeting

1800 Meeting Adjournment

Annex 3: WGMASC terms of reference for the next meeting

The Working Group on Marine Shellfish Culture [WGMASC] (Chair: P. Cranford, Canada) will meet in Copenhagen, Denmark from 10–14 April 2007 to:

a) Identify emerging shellfish aquaculture issues and related science advisory needs for maintaining the sustainability of living marine resources and the protection of the marine environment. The task is to briefly highlight new and important issues that may require additional attention by the WGMASC and/or another Expert Group as opposed to providing a comprehensive analysis;

b) complete the development of a recommended framework for the integrated evaluation of the impacts of shellfish aquaculture activities in the coastal zone by identifying a suite of tools (e.g. modelling, technologies) and indicators (ecosystem and shellfish performance) specific for monitoring ecosystem status in relation to shellfish aquaculture and for evaluating ecosystem quality objectives and effects on the productive capacity of coastal systems. This will also provide guidelines for monitoring programmes and the selection of management reference points (operational objectives) and mitigations;

c) review knowledge and report on the significance to wild stocks of bivalve aquaculture transfers between sites/countries. This will include information on what species are transported where, what records are kept, and what guidelines are in place in ICES countries related to the transfer of cultured species. Also, review and assess: the potential for transfer of non-indigenous species and diseases; the potential genetic implications for wild stocks; the impact on recruitment to existing stocks by large scale transfers, and scientific tools for decision support on cultured shellfish transfer issues; and

d) review the state of knowledge on the evidence for and effect of climate change on shellfish aquaculture distribution and production in ICES and countries world wide.

WGMASC will report by XX (to be decided jointly by WGEIM and WGMASC) April, 2008 to the attention of the Mariculture Committee.

Supporting Information

PRIORITY:	WGMASC is of fundametal importance to ICES environmental science and advisory process and addresses specific issues of the ICES Strategic Plan.
SCIENTIFIC JUSTIFICATION AND RELATION TO ACTION PLAN:	Action Plan No: 1. a) 1.1, 2.1, 3.1, 4.1 b) 2.2, 3.14, 3.3, 4.14, 4.11.3, 4.11.4 c) 2.5, 2.6, 2.10, 4.7 d) 1.3, 1.6 Term of Reference a) For the WGMASC to be responsive to the rapidly changing science advice needs of aquaculture and environmental managers, important emerging shellfish aquaculture issues need to be rapidly identified and screened for potential science advisory needs to maintain the sustainable use of living marine resources and the protection of the marine environment. The intention is for this activity to flag issues that may require future attention and communication between one or several ICES Expert Groups. The Chair of the WGMASC will cross-reference all work with the Chairs of the MCC and relevant Working Groups. Term of Reference b) Shellfish production accounts for half of the mariculture production in ICES. As such, issues related to shellfish production, in relation to the environment and technological development of the industry need to be addressed within ICES. A framework is needed for the integrated evaluation of the effects of shellfish aquaculture activities in the coastal zone consisting of a suite of tools (e.g. modelling, technologies) and indicators (ecosystem and shellfish performance) specific for monitoring ecosystem status in relation to shellfish aquaculture and for evaluating ecosystem quality objectives and effects on the productive capacity of coastal systems. Science-based decision support is needed for the development of an environmental monitoring framework, based on identification of predetermined impact limits (operational thresholds) intended to trigger shellfish culture management actions. The Chair of WGMASC will cross-reference all work with the Chairs of the MCC and the WGEIM. Term of Reference c) Different shellfish life stages are transported from hatcheries and field sites to new culture sites, and often cross international boundaries, with potential implications for the introduction of non-indigenous species and diseases and the potential for interactions with wild stocks (impact on recruitment, genetic composition, diversity and polymorphism, and physiological and morphological traits). There is a need to identify the significance of shellfish relocations on the geographic distribution of wild stock traits. The significance to wild stocks of such transfers requires information on what species are transported where, what records are kept, and what guidelines are in place in ICES countries related to the transfer of cultured species. Scientific tools for decision support on cultured shellfish transfer issues should be reviewed and assessed. The Chair of WGMASC will cross-reference all work with the Chairs of the MCC, WGEIM, WGPDMO and WGITMO. Term of Reference d) Climate variability affects the recruitment and production of important commercial species and affects site suitability for shellfish culture. Increased knowledge on the effects of climate change on shellfish culture is needed to predict and assess impacts on aquaculture distribution and production. The Chair of WGMASC will cross-reference all work with the chairs of the MCC and the WGEIM.
RESOURCE REQUIREMENTS	None
PARTICIPANTS:	Representatives of all Member Countries and specialists invited by the Chair. The Group is normally attended by some 8-12 members and guests.
SECRETARIAT FACILITIES:	Meeting facilities for 2008 WGMASC meeting and joint session with WGEIM.
FINANCIAL:	Hospitality for health breaks and lunches during 2008 meeting.

LINKAGES TO ADVISORY COMMITTEES:	ACME.
LINKAGES TO OTHER COMMITTEES OR GROUPS:	There is a working relationship with the WGPDMO, WGEIM and all the groups of the Mariculture Committee.
LINKAGES TO OTHER ORGANIZATIONS:	The work of this group is closely aligned with similar work in GESAMP, WAS, and EAS.
SECRETARIAT MARGINAL COST SHARE:	ICES:NASCO – 80:20.

Annex 4: Recommendations

RECOMMENDATION	ACTION
1. The WG recommends to the MCC that ToR a be considered completed and the documents related to "*Stress indicators in shellfish and how they may be used to diagnose incidents of cultured shellfish mortality*" be reviewed by the MCC and WGPDNO and submitted as an ICES Cooperative Research Report intersessionally.	WGMASC members, MCC, WGPDNO, ICES
2. The WG recommends to the MCC that tasks related to ToR c be completed with the general recommendation that aquaculture and fisheries management techniques be integrated to enhance scallop production stock enhancement activities. It is further recommended that industry, policy makers and scientists act to assess the benefits of such methodology and facilitate plans for their use. Fishers should be encouraged to take a key role in the development and application of those plans. It is recommended that WG documents related to "*assessing the integration of aquaculture techniques to enhance wild scallop fisheries with the view of improving the management of this resource*" be submitted as an ICES Cooperative Research Report intersessionally.	WGMASC members, MCC, ACME, ICES
3. It is recommended that further genetic studies on scallop populations be undertaken to determine if geographic-based genetic population structuring exists, which would influence the development of integrated aquaculture/wild stock management regulations.	MCC, WGAGFM, ACME
4. The WG recommends merging proposed environmental indicators for shellfish culture within existing ICZM monitoring schemes in the EU. Further analysis is needed of relevant legal and policy frameworks and the role of ICZM influencing shellfish aquaculture activities for the other ICES member states (e.g. Norway, Canada, Iceland, USA). A stronger link with the WGICZM is therefore recommended. The WG recognizes that it is not always possible to set threshold values for indictors when there is considerable natural spatial variability and that it is important to determine sampling design criteria that must be used to determine if a threshold has been passed. Although a threshold should be science-based (i.e. role of WG), it is recommended that social values be incorporated when deciding if a change is unacceptable. Shellfish farmers should be actively involved in monitoring programmes to support capacity building on the local level.	WGMASC members, WGICZM
5. The WG recognized several emerging shellfish culture issues that should be addressed (in order of priority) through ICES review/advisory activities and by ongoing research: (1) the significance to wild stocks of bivalve culture transfers between sites/countries; (2) climate change impacts on shellfish aquaculture distribution and production; (3) implications of utilizing new technologies for culturing shellfish in alternative areas (e.g. exposed and offshore); and (4) alternative and value-added uses of cultured shellfish.	MCC, ACME
6. The WG recommends to the MCC that the members of the WGMASC review and report on available knowledge on the significance to wild stocks of bivalve aquaculture transfers between sites/countries as a new ToR.	MCC
7. The WG recommends to the MCC that the members of the WGMASC review the state of knowledge related to current evidence of climate change effects on shellfish aquaculture distribution and production.	MCC

8. The WG supports and recommends overlapping meetings of the WGMASC and WGEIM in 2008 at ICES facilities in Copenhagen. Topics of joint discussion are recommended to include, among other topics, shellfish culture interactions with wild stocks, exotic species, and climate change and ecosystem management frameworks for shellfish culture.	MCC, ICES

Annex 5: PANDA. Diagnostic techniques training for European National Reference Laboratories

Table A-1. Proposition for diagnostic techniques training for European National Reference Laboratories. (PANDA: Permanent Advisory Network for Diseases in Aquaculture (www. europanda.net). See key on next page for further details.

Infectious agent	Susceptible species (in EU)	Diagnostic techniques: Histology	Cytology	PCR	PCR-RFLP	DNA Sequence	ISH	TEM	Culture	Comments
OsHV1	1, 2, 3, 4, 5			S		C	S + C	C		
Nocardia crassostreae	1, 2	S	S	S + C		C	C		C	PCR and ISH are genus specific. Culture only if sequencing is needed
Candidatus Xenohaliotis californiensis	8, 9?	S	S	S		C	C			
Perkinsus olseni	3, 4, 6, 7	S		S		C	C	Not really adapted	S	PCR needed for sequencing. Culture: RFTM. ISH only genus specific.
Perkinsus marinus	1	S		S		C	C	Not really adapted	S	PCR needed for sequencing. Culture: RFTM. ISH only genus specific.
Marteilioides chungmuensis	1, 3	S	S	S		C	C	C		PCR more specific and sensitive than histology but not strictly validated
Bonamia ostreae	2	S	S	S	C	C	C	C		PCR and ISH only genus specific
Marteilia spp.	1, 2, 10, 11	S	S	C	C	C	C	C		ISH only genus specific. PCR needed for sequencing

Key to Table A-1:

1	*Crassostrea gigas*
2	*Ostrea edulis*
3	*Ruditapes philippinarum*
4	*Ruditapes decussatus*
5	*Pecten maximus*
6	*Venerupis aurea*
7	*Venerupis pullastra*
8	*Haliotis discus hannai*
9	*Haliotis tuberculata*
10	*Mytilus edulis*
11	*Mytilus galloprovincialis*
S	Screening technique
C	Confirmatory technique
S or **C**	Validated technique
	Techniques used by most NRLs
	Techniques that should be used by NRLs (or NRLs refer to CRL for diagnosis)