

# ICES WGMASC Report 2006

ICES Mariculture Committee

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

18-20 April 2006

Galway, Ireland



International Council for the Exploration of the Sea  
Conseil International pour l'Exploration de la Mer

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## Executive summary

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- ToR a) *Stress indicators in shellfish and how they may be used to diagnose incidents of cultured shellfish mortality* (Section 4; linkages to MCC, ACME, WGPNO, WGEIM)
  - The group proposed a framework directed at farmers and aquaculture managers within which information on a range of potential stressors that act on shellfish populations could be combined with observations on the response of the animals. Additional information requirements that could elucidate the cause(s) of shellfish mortality were recommended. The framework strongly encourages the inclusion of the shellfish farmer in the information generation and assessment process.
  - The importance of baseline/background environmental data was highlighted in addition to broader considerations (temporal and spatial scale issues).
  - It was concluded that in order to fully determine the causes of mortality, a pragmatic framework must be employed encompassing an initial simple approach that accumulates and assesses information from general stress indicators and, when necessary, employs more sophisticated tools. The compilation of all diagnostic and available environmental information is an important outcome of this approach that permits all the information to be assessed together and not in isolation. The process needs to be delegated to competent agencies such that conclusions can be drawn from all of the information and appropriate mitigation measures can be recommended.
  
- ToR b) *Framework for the integrated evaluation of the impacts of shellfish aquaculture* (Section 5; linkages to MCC, ACME, WGPNO, and WGEIM)
  - Addressing this ToR requires a multi-year approach to review, provide advice and report on the linked series of activities that identify, critically evaluate and address predictions and observations of potential environmental effects. A work plan was developed to systematically address each component of this framework with a final report to be provided in 2008. This will include consideration of information presented at a special session on shellfish aquaculture and ecosystem carrying capacity at the 2007 ASC in Helsinki.
  - The WGMASC began this task by identifying information sources, including ongoing science programs, relevant to assessing potential ecosystem indicators. A list of principles and criteria was also prepared for objectively assessing the applicability of a wide range of ecosystem status indicators and thresholds specific to shellfish aquaculture.
  
- ToR c) *Utility of hatchery reared seed to enhance wild scallop fisheries* (Section 6; linkages to MCC, ACME, and WGEIM).
  - Scallop fisheries worldwide may be enhanced by good fisheries management together with the introduction of aquaculture techniques to rejuvenate and enhance stocks. There is recent evidence worldwide of success in stock enhancement of scallops. This ToR considers current enhancement practices and attempts to provide guidance on their application by encouraging communication between fishery managers and the aquaculture industry and the integration of fishery and aquaculture management practices, such that they may be developed within ICES countries. Guidance provided on scallops may be applied to other molluscan species.
  - A work plan was developed, forming two parts. Aquaculture and fishery processes were identified and considered at the 2006 meeting while the topic of integrated aquaculture/fisheries management will be addressed in 2007. The present report includes considerations of:
    - wild fisheries;
    - current regulatory frameworks;
    - availability of seed for wild fisheries and aquaculture;
    - production, cost, and pros and cons of seed supply from hatcheries vs. wild spat collection; and

- factors affecting scallop production (e.g. predation, environmental impacts including HABs).
- For the WGMASC to be more responsive to the rapidly changing science advice needs of aquaculture and environmental managers, a new ToR is recommended to commence in 2007 to identify important emerging shellfish aquaculture issues. An annual listing of issues would include a brief summary (bullet point list) of the related science advice needed 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 amongst ICES Expert Groups and Committees (Section 3; linkages to MCC, ACME, WGPNO, and WGEIM).

## **1 Opening of the meeting**

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The ICES Working Group on Marine Shellfish Culture [WGMASC], chaired by Peter Cranford (Canada), held its fourth meeting in Galway (Ireland) on 18–20 April 2006 at the Marine Institute.

The meeting was opened at 9:30 on Tuesday 18 April, with Francis O’Beirn welcoming the group to the newly constructed Marine Institute. The meeting was attended by seven participants (Annex 1). The incoming chair recognized the significant contribution of the past chair, Alain Bodoy to the instigation and development of the WGMASC. Two new members participated in a WGMASC meeting for the first time: Roman Wenne (Polish Academy of Science, Institute of Oceanology, Sopot, Poland) and Bela Buck (Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany). Three members received very late notification of this meeting as a result of late additions to the WGMASC membership lists. One member was incorrectly named (Randy Penney, Canada) and the wrong e-mail address was provided. Two new members were included in a new list that the Secretariat provided to the chair on 27 March 2006, which was too late for travel approvals to be obtained. This contributed to the relatively small number of participants.

The Chair provided a general overview of the 2005 Reports and Resolutions of the Consultative and Mariculture Committees with emphasis on matters directly related to the WGMASC. The opening plenary session led to some discussion of the role of the WGMASC within the evolving ICES framework and the strategic direction that the WGMASC would like to promote (see Section 3).

The WGMASC Terms of Reference (Annex 2) were reviewed with background provided on how each is directed at addressing the content of the ICES Strategic Plan and Action Plan.

## **2 Adoption of the agenda**

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A general discussion was held on how the WGMASC should organize the work under each of the Terms of Reference (Annex 2). 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 WGMASC and the draft report is formally accepted. Owing to the relatively small group size, not all ToRs could be addressed simultaneously, but were spread out during the meeting. The agenda (Annex 3) was formally accepted.

Subgroup leaders appointed by the WGMASC were Francis O’Beirn (ToR a), Peter Cranford (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. Subgroup leaders were also given rapporteur responsibilities for their ToR during plenary sessions.

## **3 WGMASC Strategic Planning**

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ICES is continuously scrutinising how its science and advice committees work and interact, particularly now that there is a need for an advisory structure supporting the ecosystem approach. A general discussion was held regarding the strategy of the WGMASC needed to meet the current challenges of supplying science and advice within an ecosystem approach. In other words, what do we need to do within our area of expertise to help fulfil the goals expressed in the ICES Strategic Plan and Action Plan?

The recent Workshop on Review of the ICES Committee and Expert Group Performance (WKREP held on 15 March 2006) included a discussion paper that stated that “fisheries advice is operational to a much higher degree than is the environmental advice.” However, the latter is needed to develop and implement an Ecosystem Approach in ICES advisory procedures. An important conclusion of the WKREP report was that there is an existing critical problem of communication and responsiveness between the science and advisory bodies. Communication between Expert Groups and Science Committees is limited. The role of the Science Committees has become purely administrative and there is limited scope for discussion and integration of the science from Expert Groups. The Consultative Committee concluded in a discussion document for the WKREP that the Expert Groups are generally functioning very well and the Committee is trying to build bridges between Expert Groups, improve the communication flow, encourage us to produce better Executive Summaries, and to reduce information to key highlights. WGMASC recognized the importance of addressing these key points from the Consultative Committee.

Changes to ICES structure and process, particularly related to the Advisory and Science Committees, are considered necessary to stimulate the integration of science advice. The suggestion by the Consultative Committee that coordinators may be able to take responsibility for a group of Expert Groups to improve interaction is supported by the WGMASC. The additional suggestion of having Expert Group Chairs as active members of Science Committees was also supported and may encourage greater participation and commitment at the Committee level. Communication between Expert Groups could also be achieved by promoting joint meetings (e.g. a one day overlap with plenary discussions on broader issues). Such a joint meeting needs to be planned well in advance and can best be held at the ICES headquarters in Copenhagen.

The WGMASC strategy is fundamentally linked to the ICES Mission “*to advance the scientific capacity to give advice on human activities affecting, and affected by, marine ecosystems*”. Cultured bivalves are herbivorous and eat microalgae and detritus that are naturally available in the water. Food is supplied to shellfish aquaculture by the environment and their wastes return nutrients and minerals to the ecosystem. Shellfish culture is therefore intricately and inextricably linked to the ecosystem. Utilizing an ecosystem approach to evaluating and managing aquaculture effects, and the effects of the environment on aquaculture, has been the strategy of the WGMASC since its inception.

The strategic tasks of the WGMASC are listed below in relation to specific goals identified in the 2002 ICES Strategic Plan:

- Goal 1. Understand the physical, chemical, and biological functioning of marine ecosystems.*
- Understand ecosystem structure and processes and environmental variability in shellfish aquaculture regions;
  - Evaluate effects of environment on shellfish aquaculture.
- Goal 2. Understand and quantify human impacts on marine ecosystems, including living resources.*
- Evaluate the ecosystem effects of shellfish mariculture.
- Goal 3. Evaluate options for sustainable marine-related industries, particularly fishing and mariculture.*
- Develop robust exploitation strategies for shellfish aquaculture, taking into account ecosystem complexity and uncertainty;
  - Develop environmentally sound shellfish mariculture methods;
  - Identify and develop indicators of aquaculture sustainability.
- Goal 4. Advise on the sustainable use of living marine resources and protection of the marine environment.*

- Further develop practical ways for managers to apply the ecosystem approach, including the use of indicators of sustainability for shellfish mariculture;
- Improve the basis for assessment of environmental conditions, and the status and outlook of marine ecosystems;
- Develop procedures for coastal zone management that include protocols for environmentally sound shellfish mariculture practices;
- Ensure that work conducted under Goals 1, 2 and 3 are linked to specific needs for scientific advice.

As a relatively new Working Group, work to date has been directed primarily at reviewing and reporting on the state of knowledge of shellfish aquaculture/ecosystem interactions (Strategic Goals 1 to 3 above). Producing the scientific advice that decision-makers need to ensure shellfish aquaculture sustainability will be a primary focus over the next few years (Goal 4) and we encourage the development of Terms of Reference that address this specific strategic activity. The current ToRs (Annex 2) reflect the need for science advice by the aquaculture industry (ToR a and c) and environmental managers (ToR b).

It was noted that the WGMASC has the capacity to respond quickly to current problems in the culture of shellfish by allocating some plenary work time to identifying new and developing issues (e.g. the potential effects of the transfer of shellfish spat between EU countries). However, new ToRs need to be approved by the Mariculture Committee, which only meets once a year. The provision of science advice is therefore less responsive to new issues than would be the case if there were room for some preliminary consideration of the relative importance and potential advisory needs related to emerging issues. As an output of our discussions on our strategic direction, it was recommended that a generic ToR be added to our other annual tasks that would permit the WGMASC to formally identify and prioritize new shellfish aquaculture issues and provide some preliminary direction on related science advisory needs. This recommendation is intended to accelerate the advisory process, to help justify recommendations for new ToRs, and to increase communication between Expert Groups on overlapping science advisory requirements (i.e. Ecosystem Approach).

## **4 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)**

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### **4.1 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 effect. 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.

#### 4.1.1 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 (e.g. bacteria) 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 (special 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 shellfish culture operation 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 for diagnostic techniques are provided in Table 4.1.1.1. 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). 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>).

**Table 4.1.1.1: 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								Comments
		Histology	Cytology	PCR	PCR-RFLP	DNA Sequence	ISH	TEM	Culture	
OsHV1	1, 2, 3, 4, 5			S		C	S + C	C		
<i>Nocardia crassostreae</i>	1, 2	S	S	S + C		C	C		C	PCR and ISH are genus specific. Culture only if sequencing is needed
<i>Candidatus Xenohaliotis californiensis</i>	8, 9?	S	S	S		C	C			
<i>Perkinsus olseni</i>	3, 4, 6, 7	S		S		C	C	Not really adapted	S	PCR needed for sequencing. Culture: RFTM. ISH only genus specific.
<i>Perkinsus marinus</i>	1	S		S		C	C	Not really adapted	S	PCR needed for sequencing. Culture: RFTM. ISH only genus specific.
<i>Marteilioides chungmuensis</i>	1, 3	S	S	S		C	C	C		PCR more specific and sensitive than histology but not strictly validated
<i>Bonamia ostreae</i>	2	S	S	S	C	C	C	C		PCR and ISH only genus specific
<i>Marteilia spp.</i>	1, 2, 10, 11	S	S	C	C	C	C	C		ISH only genus specific. PCR needed for sequencing

**Key to Table 4.1.1.1:**

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

## 4.2 Target audience

The target audience of this protocol is likely to be 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. When a problem is highlighted, he or she should be guided on how next to proceed. The purpose of this document is to describe the first phase 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).

## 4.3 Diagnostic process to aid in identifying potential stressors

The four underlying questions, which when considered in combination can form the basis of the diagnosis, are as follows:

### (1) Is there a visual manifestation of the problem and can it be easily described?

In an attempt to initiate a diagnosis on the shellfish stress indicators we have divided the potential responses into three categories:

- Acute mortality;
- Declining condition leading to chronic mortality; and
- Loss of culture organism.

For each category, we have attempted to describe the observed problem and relate that to a known or possible cause. We have also 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.

The three primary responses that manifest themselves for shellfish populations are broadly defined as follows;

- 1 ) Acute mortality - the loss of a significant percentage of the standing stock of cultured bivalves without any obvious sign that a potential problem existed with the stock. Table 4.3.1 outlines the observations, possible causes and some follow-on observations/investigations that would be informative to the detection process;
- 2 ) 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). Table 4.3.2 outlines the observations, possible causes and some follow-on observations/investigations that would be informative to the detection process;
- 3 ) Loss - the observation of little or no trace of the cultured bivalves, or of bivalve tissue, remaining on site. Table 4.3.3 outlines the observations, possible causes and some follow-on observations/investigations that would be informative to the detection process.

**Table 4.3.1: Possible causes of acute mortality in cultured shellfish with some recommended follow-on investigations.**

Observation	Possible Cause	Follow-on
Recent empty shells	<ol style="list-style-type: none"> <li>1. predation</li> <li>2. diseases</li> <li>3. parasites</li> </ol>	<ol style="list-style-type: none"> <li>1. look for predatory organisms (e.g. birds, crabs)</li> <li>2. send a sample for physiological and biochemical investigations,</li> <li>3. watch for holes and blisters in the shell,</li> </ol>
Shell fragments	predation	look for predatory organisms (e.g. birds, crabs)
Sulphur smell, external shell blackening	<ol style="list-style-type: none"> <li>1. anoxic event</li> <li>2. algal bloom</li> </ol>	<ol style="list-style-type: none"> <li>1. measure O<sub>2</sub> concentration in water column and review environmental recordings (if available). Note evidence of other dying organisms (e.g. fish, invertebrates). Bacterial identification.</li> <li>2. take water sample and send for further investigations (Chl analysis, taxonomy), measure O<sub>2</sub>.</li> </ol>
Water discolouration	<ol style="list-style-type: none"> <li>1. algal bloom</li> <li>2. sediment load</li> </ol>	<ol style="list-style-type: none"> <li>1. take water sample and send for further investigations (Chl analysis, taxonomy), measure O<sub>2</sub>.</li> <li>2. record secchi depth, take water samples for total suspended solids analysis.</li> </ol>
Clogged gills	<ol style="list-style-type: none"> <li>1. algal bloom</li> <li>2. sediment load</li> </ol>	<ol style="list-style-type: none"> <li>1. take water sample and send for further investigations (Chl analysis and taxonomy).</li> <li>2. observe if there is sediment obvious on gills or send a tissue sample for further investigation.</li> </ol>
Burial	<ol style="list-style-type: none"> <li>1. sedimentation</li> <li>2. storm event</li> <li>3. dredging</li> </ol>	<ol style="list-style-type: none"> <li>1. review weather recordings (strong currents and waves, tidal stage), evidence of shoreline erosion, increased riverine discharge.</li> <li>2. review weather recordings (strong currents and waves)</li> <li>3. consult with fishermen regarding fishing activities, investigate other activities (marine construction, dredge spoil disposal) in the region.</li> </ol>

**Table 4.3.2: Possible causes of declining condition in cultured shellfish with some recommended follow-on investigations.**

OBSERVATION	POSSIBLE CAUSE	FOLLOW-ON
<b>Whole animal</b>		
Shell gaping, mantle recession, discolouration	1. Low oxygen 2. Pathogen	1. Measure O <sub>2</sub> -concentration in water column or, if available, review temperature and O <sub>2</sub> recordings. Note evidence of impacts on other organisms (e.g. fish, invertebrates) 2. Collect whole animal samples for analysis.
Enlarged size of siphon openings	Low food availability	Take water sample and send for further investigations (Chl and total solids analysis and taxonomy).
Reduced attachment strength	Parasites (trematodes)	Send sample for analysis
Reduced burial depth	1. Parasites (trematodes), 2. Shallowing of sediment oxic layer	1. Send sample for analysis 2. Discolouration and smell of sediments, bacterial mats developing. Send samples for Eh, sulphide analysis.
<b>Shell condition</b>		
Shell structure	1. Physical restriction (e.g. overcrowding) 2. Contaminants 3. Speciation	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) 3. Send sample for taxonomic analysis
Reduced growth rate of stock	Food and space competition (e.g. fouling, overstocking)	Review history of culture activity focusing upon potential competing organisms and culture density
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.
<b>Tissue condition</b>		
Low meat yield	1. Food availability 2. Parasite infection	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. 2. Test for parasites (e.g. <i>Mytilicola</i> sps)
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)	Check for presence of pea crabs. Send sample for analysis.

**Table 4.3.3: Possible causes of loss of cultured shellfish with some recommended follow-on investigations.**

OBSERVATION	POSSIBLE CAUSE	FOLLOW-ON
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	Parasites (trematodes)	Send sample for analysis
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	morphometric and molecular analysis

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.

### **(2) 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. What would be important is that good communication exists between producers and their organisations and the regulatory management agencies. 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 prioritise research and investigation as well as provide resources needed to carry out such efforts.

### **(3) 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.

#### (4) **Where does the problem occur?**

Is the problem related to a specific culture type:

- 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.

## **4.4 Discussion**

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 within which the process of compiling a list of stressors that could lead to loss, acute mortality or a reduction in performance or condition of shellfish. WGMASC appreciates that the lists generated above are 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, 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.

#### 4.5 General Conclusions

- 1) Baseline data on these stress indices should be generated to enable comparison of the various systems;
  - a. 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.
  - b. 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.
- 2) An attempt will be made to identify and prioritise the cause and effect relationships of the myriad of stressors shellfish are exposed to (WGMASC 2005) Generalising these effects and identification of diagnostic tools will allow modelling of impacts.
- 3) In order to fully determine the causes of mortality, a practical system must be employed encompassing both a pragmatic, simple approach assessing general stress indicators and more sophisticated tools. The compilation of all information is an important outcome such that all the information can be considered together and not in isolation. The process needs to be delegated to competent individuals or agencies such that conclusions can be drawn from all of the information and appropriate mitigation measures can be recommended.

#### 4.6 Recommendations

- 1) The Working Group recommends to the Mariculture Committee that this ToR be developed further by the WGMASC in 2007 in order to generate as comprehensive list of stressors and responses as possible. In addition, environmental parameters should be identified and prioritised as essential information to accompany any report of shellfish mortality.
- 2) The Working Group recommends to ICES that a preliminary diagnostic guideline be developed based upon the framework described in this report. This guideline should be created by individual experts in the field of environmental stress and should provide for a comprehensive protocol to aid in the identification of causes of mortality in cultured shellfish and recommend appropriate mitigation measures.

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

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The recommended framework is to be completed by identifying a suite of tools (e.g. modelling, technologies) and indicators 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 programs and the selection of management reference points (operational objectives) and mitigations.

Environmental effects monitoring (EEM) is a central component of environmental protection and management strategies designed to minimise the consequences of anthropogenic activities (GESAMP, 1991). The purpose of any ecosystem monitoring program is not exclusively to document the temporal and/or spatial scale of impacts, but is to *prevent* potentially significant negative impacts from occurring through the responsive management of industry practices. Monitoring programs are designed to encourage the avoidance and mitigation of any harmful alteration, disruption or destruction of ecosystem structures and processes. In the case of shellfish aquaculture, the combination of ecosystem and shellfish performance monitoring (the latter can also serve as an ecosystem status indicator) can help to optimize the productivity and profitability of the culture and promotes sustainability. Frameworks for environmental management generally consist of a linked series of activities that identify, critically evaluate and address predictions and observations of environmental effects.

## 5.1 Workplan (ToR b)

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 (e.g. aquaculture site assessment, environmental risk assessment, hydrodynamic, shellfish food supply and impact prediction models, monitoring of ecosystem indicators, impact mitigation, and decision support tools for responsive ecosystem management). Addressing ToR B therefore requires the development of a multi-year plan and the progressive annual reporting on different components of the recommended ecosystem management framework for shellfish aquaculture. It is recommended to the Mariculture Committee that the WGMASC address ToR B by subdividing this large task into components that can be addressed over three years and integrated into a final report. These tasks require close linkages to the other Expert Groups, the MCC and the ACME. Joint participation of the WGEIM and the WGMASC in the development of a theme session on ecological carrying capacity of shellfish culture, to be held at the 2007 ICES Annual Science Conference, is an example of the healthy linkages and communication that currently exist. The outcomes of this session will be key to addressing some tasks under ToR B and our work plan was developed to take advantage of the timing and outcomes of the 2007 ASC.

The WGMASC reviewed the activities required to complete this task and developed the following work plan:

### 2006:

- Identify relevant information sources on management frameworks including past and ongoing science activities.
- Prepare a list of principles and criteria for assessing the utility of ecosystem status indicators specific for shellfish aquaculture.

### 2007:

- Complete a review of potential ecosystem status indicators specific to shellfish aquaculture and provide recommendations.
- Provide the scientific rationale and make recommendations on indicator thresholds (operational objectives) for triggering aquaculture and ecosystem management decisions.
- Report on options and provide recommendations on mitigation measures for shellfish aquaculture impacts.
- Co-sponsor a session on ecosystem carrying capacity, including methodologies and technologies, in relation to shellfish aquaculture at the ASC in Helsinki, Finland.

### 2008:

- Review and report on approaches for assessing and quantitatively predicting ecosystem impacts of shellfish aquaculture.
- Integrate content of preliminary ToR b reports (2006 to 2007) on the major components of an integrated framework for the ecosystem-based management of shellfish aquaculture and prepare the final ToR report to the MCC. This is viewed as a potential ICES publication.

## 5.2 Criteria for identifying and selecting indicators of ecosystem status

It is not solely the responsibility of scientists to determine what constitutes an unacceptable impact as there are important socio-economic considerations to any such discussion. Our role as scientists is to provide advice from the sole perspectives of the ability to:

- characterize ecosystem status and aquaculture impacts (indicator identification); and
- identify factors that could indicate the potential consequences to marine ecosystems from changes in this status (threshold recommendations).

This requires that we do not consider the potential consequences to industry or society stemming from our recommendations related to this ToR. Such socioeconomic considerations are highly relevant to the development of an aquaculture management framework, but are outside the scope of our activities and expertise. Environmental conservation and protection legislations in place within ICES countries are also important considerations for the selection of indicators, and particularly for the setting of ecosystem operational objectives (management triggers or thresholds). However, our focus was on developing a generic science-based approach to assessing ecosystem status and this does not consider potential modifications that may be needed to suit the legislation of individual countries.

A consistent and objective approach is needed to identify and assess the attributes and potential applications of a broad spectrum of potential ecosystem indicators and management decision thresholds. The ranking of the suitability of ecosystem status indicators can be somewhat subjective in that it requires professional judgements that can be weighted towards each scientist's particular field of interest. Preliminary efforts were taken to promote impartiality and objectivity by establishing indicator selection criteria and ensuring that a firm scientific rationale exists for including the indicator in the assessment. The following criteria were developed for screening the suitability of indicators in what we hope will be a WGMASC consensus building exercise:

- 1) Addresses the known and potential effects of shellfish aquaculture, particularly during the grow-out phase when biomass per unit area is greatest.
- 2) Provides information on the severity of the potential impact to ecosystem structure and dynamics.
- 3) Is generally applicable to all cultured species.
- 4) The indicator and measurement approach needs to be able to detect an impact over the actual temporal and spatial scale of the effect. The targeted impact should be measurable over a variety of scales including "local" (directly under and adjacent to the culture structure), "lease" (footprint), "bay" (the embayment or coastal management area), and "regional" (larger coastal areas with similar environmental conditions) geographic scales. Ideally, an indicator measurement taken at a specific sampling site should provide information on local impacts as well as impacts occurring over a much larger geographic scale.
- 5) The natural degree of variation in indicator values expected at aquaculture sites should be less than the magnitude of the potential impact. Variation is directly related to the statistical design required to conduct effective and practical monitoring programs (e.g. identification of sample size) and the ability of the indicator to detect a known impact (i.e. statistical power).
- 6) The accuracy and precision of the measured indicator value.
- 7) Low-cost indicators of operational impacts are preferable if they are able to contribute to the conservation and protection of marine ecosystems as effectively as more costly approaches. Cost estimates should include operational and capital costs associated with initial setup and sequential surveys and account for robust sampling design considerations (e.g. number of survey stations and sample size) that are reflected in the cost.

- 8) Indicator data should be easily and intuitively interpreted by aquaculture and environmental managers (all stakeholders).
- 9) The availability of established and/or defensible threshold values that define significant changes in ecosystem status.
- 10) The ability to specifically identify aquaculture impacts in systems exposed to multiple stressors.
- 11) For an ecosystem approach to management to be effective, the time-frame between ecosystem status 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.

The above criteria are based on WGMASC expertise, the reference listed in the following section, and the conclusions of similar exercises undertaken in the EU (Annex 6) and Canada (Annex 7)

### 5.3 Selected References on Criteria for Indicator Selection

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- Rice, J. 2003. Environmental health indicators. *Ocean and Coastal Management*, 46: 235–259.
- Segnestam, L. 2002. Indicators of environment and sustainable development, The World Bank Environment Department: 61 p.

## **6 Prepare a report assessing the utility of hatchery reared seed to enhance wild scallop fisheries with the view of improving the management of this resource (ToR c)**

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### **6.1 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 reseedling, in order to sustain the production. Mussels produced by cultivation (hatchery or spat collectors) can also be used in restocking programmes, while fished spat and adults mussels can be used for aquaculture. Oyster production in some countries still heavily relies on the availability of natural spat settlement, even for restoration programmes. 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 regulation, such as the relative costs of leases for aquaculture and taxes on enhancement of fisheries (e.g. Rade de Brest). 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 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?

### **6.2 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. 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. 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 minimising 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 and 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 have considered possible recommendations for the future.

### **6.2.1 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.

### **6.2.2 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 6.2.4.1.

### **6.2.3 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. 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 has shown that the production costs of scallops of a commercial size (10 cm), strongly depends on the final capture rate: 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). Information on recapture success may be obtained from studies of areas exclusively utilized for seeding. However, such space in France has declined after colonisation of former scallop grounds by *Crepidulas*.

### **6.2.4 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 (Pacheco, 2003) in *A. purpuratus*, offering feeding and protective benefits. Coralline red algae, maerl, can provide a nursery area for scallops (Fraser, pers. comm.) and is the preferred attachment for queen scallops (Kamenos *et al.*, 2004a,b and c).

Natural pectinid spat settlement is unreliable and difficult to predict, 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 6.2.4.1: 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 in synchrony with natural cycles	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.
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	

### 6.2.5 Hatchery Production of Seed

The production of seed from hatcheries offers a more controlled environment for a more reliable, consistent supply of spat. Wild broodstock is introduced during spawning cycles, e.g. early spring and conditioned to spawn. Spat are transferred to sea in summer to early autumn at 10–15 mm into Pearl Nets or directly onto the seabed. A good quality, pathogen free water supply is essential for successful hatch and post hatch of animals. Post hatch problems have been identified in *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 and Scotland). Capital investment and trained manpower in practical and technical issues are essential in hatchery development, where good husbandry is a paramount consideration.

In years of good natural spat fall where hatchery demand is low, a contracted supply to farmers is essential for the hatchery to remain in business.

### 6.2.6 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. Recent reports 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. 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. Future consideration of triploidy to obtain sterility and increase rate of growth may be considered in hatchery production. This treatment would also limit the impact of introgression to indigenous populations.

### 6.2.7 Factors Affecting Scallop Production

#### 6.2.7.1 Predation

During its life cycle, the scallop is subject to predation from various organisms, particularly seastars, sea bream, crabs and starfish (Christophersen and Magnuson, 2005). Adult scallops (> 50 mm in *Pecten maximus*) have the ability to resist predator attack by swimming to escape, however juveniles are more prone to predation. 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, almost 100% mortality from crabs and starfish was observed in spat released directly onto the seabed post settlement (Howell, pers com), while experience in New Zealand reported 15% survival of spat transported 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 two years old (Howell, pers. comm.). In Japan, spat was released at 30 mm on low mud substrate to obtain optimum survival of *Patinopecten yessoensis* (Ventila, 1982).

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 and Fraser, 1984). Therefore survival from the juvenile stage, to harvest, is expected to be high.

### **6.2.7.2 Environmental impacts**

Both aquaculture and wild fisheries for scallops may produce an environmental impact on the marine environment, 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 reseeded spat onto protected areas. Scallops in shallow waters can be collected by divers. 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. Consultation with local authorities and current legislation is advocated well in advance of movements between health zones.

### 6.2.7.3 Harmful algal blooms

Shellfish toxins such as paralytic and diarrhetic shellfish poisons (PSPs and DSPs) occur regularly in bivalves harvested from Scottish waters with both groups responsible for periodic harvesting bans, with domoic acid being responsible for closures in the majority of Scottish scallop fisheries in 1999 (Gallacher *et al.*, 2000). 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. 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.

### 6.2.7.4 Regulations

Two types of regulations are to 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 and Wild Birds Directive 79/409/ECC. These directives do not affect the supply of seed from hatcheries or from natural spat settlement, except where habitats are protected or when reseeded from non approved or protected areas - as defined in the directives. 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.

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 reseeded from hatchery-reared spat, as large investments are made to produce and to growth these animals.

## 6.3 Aquaculture and Fisheries Management

The section was briefly discussed by the WGMASC with a view towards addressing it further in 2007. An overview of the general topics to be addressed is as follows:

- 1) Over fishing and stock replenishment;
- 2) Establishment of larger spawning biomass;
- 3) Increase harvest potential over long term;
- 4) The beneficial effect on adjacent scallop beds;
- 5) Restocking – rebuild spawning biomass, by the introduction of juveniles – severely depleted stock;
- 6) Stock enhancement – augment, increase productivity of an operational fishery – increase recruitment;
- 7) Management of closed areas and success stories worldwide:

- During a four-year closure in Georges Bank, *P. magellanicus* biomass increased up to 14 times;
  - Significant density increases in the Irish sea after the 1989-98 closure
  - Observations of changes in population size structure to historical conditions in closed areas;
- 8) Aquaculture to increase sustainable production of marine resources (e.g. improved harvest, optimize stocking densities to maximize yield):
- Ranching in Japan, which began following a decline of scallop stocks in the 1960s, has resulted in a 10 fold increase in production;
  - Enhance using hatcheries and farm techniques, then release; 25–30% survival, harvest 20% (Ventilla, 1982), 25% recovery in France (Dao, 1992), NZ 50% -improved handling, harvest at two years (Arbuckle, 2000);
- 9) Control of predators;
- 10) Rotational fishing to stabilise areas, without enhancement;
- 11) The key role of the fisherman;
- 12) Market expansion with value added product.

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## Annex 1: List of participants

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## Annex 2: WGMASC Terms of Reference 2005

The **Working Group on Marine Shellfish Culture** [WGMASC] (Chair: Peter Cranford, Canada) will meet in Galway, Ireland, from 18–20 April 2006 to:

- a) 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;
- 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) prepare a report assessing the utility of hatchery reared seed to enhance wild scallops fisheries with the view of improving the management of this resource. Culture techniques, population dynamics parameters, such as growth to the commercial size and mortality, monitoring during the on-growing stages, yields, number and cost of seeded spat vs. fished adults, potential impacts of culture and dredging should be collected and assessed from different sources during intersessional work.

WGMASC will report by 20 May 2006 for the attention of the Mariculture Committee.

### Supporting Information

<b>PRIORITY:</b>	WGMASC is of fundamental importance to ICES environmental science and advisory process and addresses specific issues of the ICES Strategic Plan.
<b>SCIENTIFIC JUSTIFICATION AND RELATION TO ACTION PLAN:</b>	<p>Action Plan references:</p> <p>a) 2.6, 3.4, 3.11, 4.7</p> <p>b) 1.10, 3.10, 3.14, 4.6, 6.3</p> <p>c) 2.12, 3.11, 4.7</p> <p><b>a)</b> Shellfish production is based on the use of the natural productivity of coastal waters as a source of food. Shellfish require a clean environment and is, in essence, integrating the environmental conditions of the growing area. Unexplained mortalities have an immediate negative effect on both producers and market share. These can be caused by predation, HAB, diseases, pollution, and water quality or any combination thereof. Stress in animals can be caused by either chronic or acute extrinsic factors that may act to decrease the fitness of the animal or to cause its premature death. Use will be made of the biological effects of contaminants literature that is available within ICES. Chronic factors will often be manifested by changes in the overall health of the animal (i.e., in a stepwise cellular-tissue-organ-physiological levels). Acute factors produce immediate responses that may only show up at the molecular/cellular levels. Therefore, detecting acute effects is usually done with biochemical techniques. Different bio-indices will be reviewed and their usefulness determined: adenylate energy charge (AEC), heat shock proteins, total oxy-radical scavenging capacity (TOSC), glycogen content, metallothioneins (MT), cytochrome P4501A1 activity, DNA damage, total lipids and histology. Work will also be cross-referenced with WGEIM.</p>

	<p><b>b)</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. The effects of the environmental perturbations on shellfish production are dramatic and sudden. There is a need to identify the causes of potential impacts and their effects on the production of shellfish, in order to establish the requirements for the industry in terms of water quality, ecological perturbations and biological competitors. The information will also be useful for determining the ecological requirements for shellfish production in coastal areas. The Working Group has given priorities to the different impacts : 1- Carrying capacity (Hydrographic factors, Primary productivity, food supply), 2- Predation, 3- fouling, 4- HAB Blooms,5- Disease, 6- Pollution (water quality). The Chair of WGMASC will cross-reference all work with the Chairs of WGEIM and WGHABD</p> <p><b>c)</b> Spat availability is of a primary importance for the shellfish industry. It relies upon both the hatchery production, as reviewed recently by WGMASC, and the collection of spatfall from the field. Nowadays, many of the recent development of shellfish production would be based on hatchery produced spat, depending on the country. This is observed for scallop production, which are either reared in open waters by means of longline culture or bottom culture, dived or dredged in coastal areas. Stocks depletion in scallops beds, in certain countries, have led to the use of hatchery reared spat for reseeded, in order to sustain the production. Also mussels produced by cultivation can be used in restocking programmes, while fished mussels can be farmed as spat or adults. Oyster production still heavily relies on the availability of natural spat settlement, even for restoration programmes. Therefore, a continuum exists for the shellfish production, from fisheries to aquaculture. This aspect and the scallop industry is not addressed by any of the ICES WG (MCC or LRC), while management issues and concerns, related with such a variety of production means, are growing in ICES countries. Several aspects need to be specifically addressed, in reference to the ICES action plan, and according to the interactions among different science committees (MCC and LRC – implication of ranching on harvesting wild populations.</p>
<b>RESOURCE REQUIREMENTS:</b>	None
<b>PARTICIPANTS:</b>	Representatives of all Member Countries and specialists invited by the Chair
<b>SECRETARIAT FACILITIES:</b>	None.
<b>FINANCIAL:</b>	None.
<b>LINKAGES TO ADVISORY COMMITTEES:</b>	ACME
<b>LINKAGES TO OTHER COMMITTEES OR GROUPS:</b>	MCC, WGPDMO, WGEIM
<b>LINKAGES TO OTHER ORGANIZATIONS:</b>	WAS, EAS
<b>SECRETARIAT MARGINAL COST SHARE:</b>	

## **Annex 3: Agenda**

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### **Tuesday 18 April 2006**

- 09:30 Welcome from Marine Institute and meeting arrangements – Francis O’Beirn
- 09:45 Introductions and update on ICES activities – Peter Cranford
- General Discussion of Terms of Reference
  - Adoption of agenda
  - Designation of subgroup leaders and rapporteurs
- 10:30 *Health Break*
- 11:00 Plenary to develop workplan and identify subgroups.
- 12:30 **Lunch**
- 13:30 Subgroup sessions on ToR A and Tor C
- 15:00 *Health Break*
- 15:15 – 18:00 Continue ToR A and Tor C subgroup sessions

### **Wednesday 19 April 2005**

- 09:30 Plenary – overview work status
- Reconvene ToR A and ToR C subgroup sessions
- 10:30 *Health Break*
- 11:00 Reconvene ToR A and ToR C subgroup sessions
- 13:00 **Lunch**
- 14:40 Complete drafting of ToR A and ToR C responses.
- 15:00 *Health Break*
- 15:15 – 18:00 Plenary on ToR B with presentations on relevant Canadian and French science activities followed by ToR B drafting

### **Thursday 20 April 2005**

- 09:00 Final subgroup drafting of ToR text.
- 10:30 *Health Break*
- 11:00 Plenary Session.
- Review ToR draft reports
- 13:00 **Lunch**
- 14:00 Revise draft reports in subgroups
- 15:30 *Health Break*
- 16:00 Plenary Session:
- Review and adoption of the scientific text of the report (deadline April 25)
  - Discussion on Recommendations
  - Prepare Executive Summary
  - Discussion on new Terms of Reference
  - Location of next meeting
  - Any other business
- 19:00 Meeting Adjournment

## Annex 4: WGMASC terms of reference 2006

The Working Group on Marine Shellfish Culture [WGMASC] (Chair: Peter Cranford, Canada) will meet in Halifax, Canada, from 27–29 March 2007 to:

- a) 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;
- 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) prepare a report assessing the utility of hatchery reared seed to enhance wild scallops fisheries with the view of improving the management of this resource. Culture techniques, population dynamics parameters, such as growth to the commercial size and mortality, monitoring during the on-growing stages, yields, number and cost of seeded spat vs. fished adults, potential impacts of culture and dredging should be collected and assessed from different sources during intersessional work.
- d) 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.

WGMASC will report by XX May 2007 for the attention of the Mariculture Committee.

### Supporting Information

<b>PRIORITY:</b>	WGMASC is of fundamental importance to ICES environmental science and advisory process and addresses specific issues of the ICES Strategic Plan.
<b>SCIENTIFIC JUSTIFICATION AND RELATION TO ACTION PLAN:</b>	<p>Action Plan references:</p> <ul style="list-style-type: none"> <li>a) 2.6, 3.4, 3.11, 4.7</li> <li>b) 1.10, 3.10, 3.14, 4.6, 6.3</li> <li>c) 2.12, 3.11, 4.7</li> <li>d) 1.10, 3.10, 5.14, 7.20</li> </ul> <p><b>a)</b> Shellfish production is based on the use of the natural productivity of coastal waters as a source of food. Shellfish require a clean environment and is, in essence, integrating the environmental conditions of the growing area. Unexplained mortalities have an immediate negative effect on both producers and market share. These can be caused by predation, HAB, diseases, pollution, and water quality or any combination thereof. Stress in animals can be caused by either chronic or acute extrinsic factors that may act to decrease the fitness of the animal or to cause its premature death. Use will be made of the biological effects of contaminants literature that is available within ICES. Chronic factors will often be manifested by changes in the overall health of the animal (i.e., in a stepwise cellular-tissue-organ-physiological levels). Acute factors produce immediate responses that may only show up at the molecular/cellular levels. Therefore, detecting acute effects is usually done with biochemical techniques. Different bio-indices will be reviewed and their usefulness determined: adenylate energy charge (AEC), heat shock proteins, total oxy-radical scavenging capacity (TOSC), glycogen content, metallothioneins (MT), cytochrome P4501A1 activity, DNA damage, total lipids and histology. Work will also be cross-referenced with WGEIM.</p>

	<p><b>b)</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. The effects of the environmental perturbations on shellfish production are dramatic and sudden. There is a need to identify the causes of potential impacts and their effects on the production of shellfish, in order to establish the requirements for the industry in terms of water quality, ecological perturbations and biological competitors. The information will also be useful for determining the ecological requirements for shellfish production in coastal areas. The Working Group has given priorities to the different impacts : 1- Carrying capacity (Hydrographic factors, Primary productivity, food supply), 2- Predation, 3- fouling, 4- HAB Blooms,5- Disease, 6- Pollution (water quality). The Chair of WGMASC will cross-reference all work with the Chairs of WGEIM and WGHABD</p> <p><b>c)</b> Spat availability is of a primary importance for the shellfish industry. It relies upon both the hatchery production, as reviewed recently by WGMASC, and the collection of spatfall from the field. Nowadays, many of the recent development of shellfish production would be based on hatchery produced spat, depending on the country. This is observed for scallop production, which are either reared in open waters by means of longline culture or bottom culture, dived or dredged in coastal areas. Stocks depletion in scallops beds, in certain countries, have led to the use of hatchery reared spat for reseedling, in order to sustain the production. Also mussels produced by cultivation can be used in restocking programmes, while fished mussels can be farmed as spats or adults. Oyster production still heavily relies on the availability of natural spat settlement, even for restoration programmes. Therefore, a continuum exists for the shellfish production, from fisheries to aquaculture. This aspect and the scallop industry is not addressed by any of the ICES WG (MCC or LRC), while management issues and concerns, related with such a variety of production means, are growing in ICES countries. Several aspects need to be specifically addressed, in reference to the ICES action plan, and according to the interactions among different science committees (MCC and LRC – implication of ranching on harvesting wild populations.</p> <p><b>d)</b> 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.</p>
<b>RESOURCE REQUIREMENTS:</b>	None
<b>PARTICIPANTS:</b>	Representatives of all Member Countries and specialists invited by the Chair
<b>SECRETARIAT FACILITIES:</b>	None.
<b>FINANCIAL:</b>	None.
<b>LINKAGES TO ADVISORY COMMITTEES:</b>	ACME
<b>LINKAGES TO OTHER COMMITTEES OR GROUPS:</b>	MCC, WGPDMO, WGEIM
<b>LINKAGES TO OTHER ORGANIZATIONS:</b>	WAS, EAS
<b>SECRETARIAT MARGINAL COST SHARE:</b>	

## Annex 5: Recommendations

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RECOMMENDATION	ACTION
1. WGMASC recommends that ToR a remain active in 2007 to complete a framework based on stress indicators in shellfish for industry to develop a code of practice for documenting case histories detailing mortality events and for developing a field diagnoses key, follow-up procedures and identifying regional regulatory contacts.	MCC
2. WGMASC recommends that ToR b remain active in 2007 to complete a review of potential ecosystem status indicators specific to shellfish aquaculture and provide recommendations, to provide the scientific rationale and make recommendations on indicator thresholds (operational objectives) for triggering aquaculture and ecosystem management decisions, and to report on options and provide recommendations on mitigation measures for shellfish aquaculture impacts.	MCC
3. WGMASC recommends that ToR c remain active in 2007, including the review and reporting on integrated management approaches for aquaculture and wild fisheries to achieve long term sustainability without compromising marine ecosystem. In addition, potential risks with the transport of shellfish for restocking purposes, including; the introduction and transmission of pests, disease and hitchiker species and any changes in the genetic makeup of the native bivalve population will be reviewed and reported on.	MCC
4. WGMASC recommends that a new reoccurring ToR be added to identify and report on emerging and priority shellfish aquaculture issues and related science advisory needs for maintaining the sustainability of living marine resources and the protection of the marine environment. This is to increase working group responsiveness to clients and to promote communication of new issues and advisory needs between Expert Groups.	MCC

## **Annex 6: Criteria for assessing indicators: ECASA project**

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### **ECASA WP 2 (Friday, 17 December 2004)**

#### *Annotated sheet for indicators related to the impact of aquaculture on the environment*

#### *Criteria for assessing indicators*

**8-Indicators assessment.** We will need to select the most appropriate indicators to be proposed for EIA and site selection. Please suggest a quotation for this indicator for the following criteria (from A, perfectly adequate, to E, not relevant), to help evaluating the indicator within WP 4. Additional comments are welcome.

- **Direct relevance to objectives:** The indicator selection must be closely linked to the requirements of the EU: Use for environmental impact assessment and site selection. This aspect should be detailed.
- **Clarity in design.**

It is important that the selected indicators are defined clearly in order 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 need 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:** The meaning and usefulness of the indicator should easily be understood by stakeholders. They would preferably use the levels of dissolved oxygen, rather of sulphide concentrations.

## **Annex 7: Terms of Reference: Canadian Workshop**

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### **National Peer-Review Workshop**

#### **Aquaculture-Environment Interactions: Shellfish Aquaculture in the Marine Environment**

**February 28–March 3, 2006**

**Moncton, N.B.**

#### **Preamble**

A national workshop has been initiated to meet DFO Habitat Management's need for science advice related to the fish habitat effects of shellfish aquaculture in the marine environment.

Science advice is required to define the fish habitat effects of shellfish aquaculture, to define appropriate tools and methodologies (models, indicators and thresholds) for predicting and assessing these effects, to determine the sensitivity of selected fish habitats to these effects, and to enhance national coherence between regional decision-making approaches.

In addition to addressing farm-scale habitat effects under the *Fisheries Act*, there is also a need to consider the importance of ecosystem-scale and cumulative effects of shellfish aquaculture activities... This consideration of ecosystem effects requires sound science to inform decision-making. Developing a fully integrated ecosystem-based approach, however, is beyond the scope of this process and would detract from its focus; rather the goal here is to provide advice on shellfish aquaculture effects that will be immediately applicable to Habitat Management site-specific decision-making and that may be pertinent to forthcoming ecosystem management initiatives. An attempt will be made, where scientific knowledge exists, to consider tools and methodologies for assessing both farm-scale and ecosystem-wide effects.

This advice on tools and methodologies will assist DFO's Habitat Management in reviewing shellfish aquaculture site applications and in assessing ongoing aquaculture operations in the marine environment. In addition, it will provide a basis for any future, more detailed examinations of aquaculture activities in a site-specific, or an ecosystem-based management context.

#### **Science Advice**

Peer-reviewed science advice will be generated to, where possible, address the following questions:

- a) What are the positive and the negative effects (benthic and/or water column) of marine shellfish aquaculture on fish habitat? How do shellfish aquaculture effects on fish habitat differ from the 'natural' effects of wild shellfish? What are the effects of the physical structures used in shellfish aquaculture on fish habitat (including lines, socks, bags, predator control devices, etc.)? How can these effects be assessed or measured?
- b) What chemical, biological or physical indicators developed and in use for monitoring the farm-scale fish habitat effects of marine finfish aquaculture are applicable to monitoring shellfish aquaculture effects? Describe the thresholds that apply. What other habitat indicators are available specifically to measure these shellfish aquaculture effects? What are the thresholds for these potential indicators?

**NOTE: A threshold should be defined as a point where significant changes to fish habitat can be identified. It is equally important for the science advice to identify the threshold as it is to describe the change to habitat that is associated with the threshold.**

- c) What modeling methodologies or techniques are available to provide predictions of the potential effects of shellfish aquaculture operations on the marine environment? What are the advantages and disadvantages of these methodologies or techniques?
- d) What are the cumulative and far-field effects of shellfish aquaculture in fish habitat? How can the cumulative fish habitat effects of shellfish aquaculture (*e.g.* marine eutrophication, oxygen or phytoplankton depletion, community shifts, exceeding carrying capacity) be quantified? What tools or indicators are useful for quantifying the far-field or ecosystem-scale fish habitat effects of shellfish aquaculture? What are the advantages and disadvantages of these tools or indicators?
- e) What types of fish habitat are likely to be affected by shellfish aquaculture? How sensitive (in relative or absolute terms) are these habitats to shellfish aquaculture effects?

### **Working Papers**

The following working papers, each focusing on different themes, will inform the development of science advice. Where applicable, all working papers should include consideration of how regional and operational differences impact the applicability of tools and approaches for assessing shellfish aquaculture effects on fish habitat.

#### **Paper 1 *Identification of shellfish aquaculture effects on fish habitat***

- Overview of bivalves; shellfish aquaculture; ecological role of bivalves in natural habitat;
- Identification of effects of shellfish aquaculture on fish habitat.

#### **Paper 2 *Indicators and thresholds to assess the effects of shellfish aquaculture on fish habitat***

- Benthic, pelagic and shellfish performance indicators and thresholds, including near-, far-field and cumulative effects;
- Monitoring frameworks for assessing fish habitat effects of shellfish aquaculture and methodologies, including case studies.

#### **Paper 3 *Modeling approaches to assess the potential effects of shellfish aquaculture on the fish habitat***

- Modeling near-field benthic effects of shellfish farms (using DEPOMOD);
- Biogeochemical modelling; ecosystem-based modelling.

#### **Paper 4 *Cumulative and far-field fish habitat effects of shellfish aquaculture***

- Identification of far-field effects (*i.e.* types, extent and consequences), and cumulative effects of shellfish aquaculture on fish habitat;
- Determination of likelihood of far-field and cumulative effects.

#### **Paper 5 *Determination of habitat sensitivity to shellfish aquaculture effects***

- Case studies exploring the sensitivity of shellfish aquaculture on fish habitat:
  - Effects of bottom oyster aquaculture on eelgrass;
  - Intertidal shellfish aquaculture in Baynes Sound;
  - Seabed classification in a mussel farming bay.

### **Process and Outputs**

At the meeting a review of the papers will seek to determine whether the conclusions presented in the working papers are credible, supported by scientific data and complete

relative to global knowledge. Peer-reviewed advice to address the questions posed by DFO Habitat Management will also be developed.

Within four weeks of the meeting, papers will be revised, and published advice will be provided to Habitat Management in the form of a Canadian Science Advisory Secretariat (CSAS) Science Advisory Report. Discussions and results from the workshop will also be documented in a CSAS Proceedings document.