

# ICES WGAQUA REPORT 2013

SCICOM STEERING GROUP ON HUMAN INTERACTIONS ON ECOSYSTEMS

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## Report of the Working Group on Aquaculture (WGAQUA)

18-22 March 2013

Palavas, France



ICES

International Council for  
the Exploration of the Sea

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## Executive summary

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The WGAQUA, chaired by Karin Boxaspen, Norway, Peter Cranford, Canada and Pauline Kamermans, The Netherlands, met for the first time from 18 to 22 March 2013 in Palavas, France and was attended by 24 participants from 12 ICES countries (Annex 1). Based on a discussion on the direction of the new Aquaculture Expert Group it was recognized that aquaculture activities take place in a natural dynamic environment, where effects are not the same for each scale (local, regional, national, international). Science-based thresholds or tipping points and uncertainties need to be identified as well as the reversibility of a change. Links with stakeholders are very important. A synthesis was prepared of reports by ICES SGs and WGs related to sustainable aquaculture on the environmental dependence and effects of aquaculture and on science advice provided. This activity clearly demonstrates that ICES has been highly active over the last decade in reviewing the state of knowledge of the environmental dependence and effects of aquaculture and in the provision of advice and recommendations related to the integrated management of sustainable aquaculture (e.g. performance indicators, risk assessments, monitoring programs, generic and specific management frameworks, strengthening stakeholder inclusion in decision-making). The review of past activities will strengthen linkages between the WGAQUA and other expert groups and was helpful in identifying aquaculture issues that have not yet received adequate attention from ICES. Various suggested emerging topics were compared to the reports, recommendations and advice of earlier groups and there is a relative large overlap. This signifies that some of the topics while maybe not new or emerging they still stand as unresolved and central. The topics relevant to WGAQUA were separated from topics more thematically suited for other groups of ICES. Eight new ToRs were identified. These were grouped under three themes: Benthic Effects led by Raymond Bannister, Pest Management led by Dave Jackson and Ecosystem Interactions led by Chris McKindsey. Since the nature of the meeting was mostly planning and discussing topics to work on in the new EG no science highlights can be reported in Year 1. A Theme Session for the Annual Science Conference in 2014 was developed. Title: The application of science for ecosystem-based management of aquaculture. Member states have asked if ICES can give advice related to the sustainability of aquaculture. WGAQUA was formed, in part, to facilitate the provision of science advice on aquaculture issues and to attract a broad mix of finfish, shellfish and macroalgal aquaculture scientists. The membership of WGAQUA currently stands at 45 scientists from 14 ICES member states. WGAQUA chairs will contact delegates to seek additional representation for macroalgae plus remaining ICES states. A Science Advice co-chair has been tasked specifically with coordinating group responses to formal advisory requests. WGAQUA recommends that ACOM initiate the process of drafting specific advice questions for presentation to WGAQUA members at the 2014 annual meeting. The Science Advice chair is available to participate as required in developing these questions and for ensuring a timely response by WGAQUA to each query. Science advice on aquaculture usually includes not only ecological and technical, but also socio-economic aspects. The present membership does not include experts with a socio-economic background. SGSA was created specifically to deal with these issues. Therefore, WGQUA recommends SGSA be invited to join WGAQUA to increase expertise.

## 1 Administrative details

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**Working Group name**

Aquaculture

**Year of Appointment**

2013

**Reporting year within current cycle (1, 2 or 3)**

1

**Chair(s)**

Karin Boxaspen, Norway

Peter Cranford, Canada

Pauline Kamermans, The Netherlands

**Meeting venue**

Palavas, France

**Meeting dates**

18-22 March 2013

## **2 Terms of Reference a) – z)**

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ToR a. Synthesize reports and recommendations by WGAGFM, WGPDMO, WGH-ABD, and WGECO on the environmental dependence and effects of aquaculture.

ToR b. Synthesize previous science advice provided by ICES SGs and WGs related to sustainable aquaculture.

ToR c. Identify emerging aquaculture issues and related science advisory needs for maintaining the sustainability of living marine resources and the protection of the marine environment.

### 3 Summary of Work plan

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Year 1	Organize the work of WGAQUA and possibly propose new EGs. Discuss chairs for WGAQUA and possible new EGs. Develop workplan for ToRs depending on attendance (number of people and their expertise). Evaluate Outreach/PR activities and develop outreach plan for Year 2.
Year 2	Work on ToRs depending on attendance (number of people and their expertise). Evaluate Outreach/PR activities and develop outreach plan for Year 3.
Year 3	Finalize products depending on attendance (number of people and their expertise). Discuss future of group.

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#### **4 List of Outcomes and Achievements of the WG in this delivery period**

- A synthesis was prepared of reports and recommendations by SGSA, WGAGFM, WGEIM, WGICZM, WGITMO, WGMASC, WGPDMO on the environmental dependence and effects of aquaculture and on science advice provided by ICES SGs and WGs related to sustainable aquaculture. This activity clearly demonstrates that ICES has been highly active over the last decade in reviewing the state of knowledge of the environmental dependence and effects of aquaculture and in the provision of advice and recommendations related to the integrated management of sustainable aquaculture (e.g. performance indicator selection, methodologies and objectives, risk assessment approaches, monitoring programs, generic and specific management frameworks, strengthening stakeholder inclusion in decision-making ...). The review of past activities will strengthen linkages between the WGAQUA and other expert groups and was helpful in identifying aquaculture issues that have not yet received adequate attention from ICES.
- Various suggested emerging topics were compared to the reports, recommendations and advice of earlier groups and there is a relative large overlap. This signifies that some of the topics while maybe not new or emerging they still stand as unresolved and central. The topics relevant to WGAQUA were separated from topics more thematically suited for other groups of ICES. Eight new ToRs were identified. These were grouped under three themes: Benthic Effects led by Raymond Bannister, Pest Management led by Dave Jackson and Ecosystem Interactions led by Chris McKindsey.
- A Theme Session for the Annual Science Conference in 2014 was developed. Title: The application of science for ecosystem-based management of aquaculture. Conveners: Dave Jackson (Ireland), Henrik Hareide (Norway), Heather Moore/Adele Boyd (UK), Neil Auchterlonie (UK). This theme session is designed to act as a platform for interaction between the main groups involved within the aquaculture sector, namely;
  - Scientists who develop the evidence and knowledge base,
  - Regulators and policy-makers who set the management and regulatory frameworks and
  - Those in the aquaculture industry who work within the regulatory framework and depend on the development of an appropriate knowledge base to enhance and improve production of aquaculture products.

## 5 Progress report on ToRs and workplan

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- Discussions took place on the direction and desired structure of the new Aquaculture Expert Group (WGAQUA). The members were presented reviews of the ICES discussion paper on aquaculture (and related documents) and adopted the proposed mission and vision of this new expert group:

***Vision:***

*A diverse aquaculture sector in ICES member states that will meet the increasing demand for seafood and products while providing jobs, products, and services in harmony with healthy, productive, and resilient freshwater and marine ecosystems.*

***Mandate:***

*Improving the sustainability of aquaculture in the ICES area through state-of-the-art science and advice*

It was recognized that aquaculture activities take place in a natural dynamic environment, where effects are not the same for each scale (local, regional, national, international). Science-based thresholds or tipping points and uncertainties need to be identified as well as the reversibility of a change. Links with stakeholders are very important (e.g. EATIP, USDA). A workshop with EATIP was proposed. Since aquaculture is more related to agriculture than to fisheries, it was suggested that FAO examples may provide guidelines on how to structure our group. It was decided that the structure of WGAQUA should be responsive to the ToRs being addressed during each 3-year reporting cycle. It was decided to identify ToR Theme Leaders to assist the chairs in the integration of the different ToR activities during meetings and report preparation. Any science advisory activities formally requested by ACOM are to be coordinated within WGAQUA by the Science Advice Chair with responses provided outside the 3-year ToR reporting cycle (i.e. more timely response).

- ToR a and b were completed and are reported in Annex 3. Annual reports prepared by several ICES expert groups (SGSA, WGAGFM, WGEIM, WGICZM, WGITMO, WGMASC, WGPDMO) were examined to address ToRa and ToRb at the same time. WGHABD (Harmful Algal Bloom Dynamics) and WGECO (Ecosystem Effects of Fishing Activities) were not included in this analysis because their work was previously reviewed, often on an annual basis, by other working groups (e.g. WGMASC, WGEIM and WGICZM) that were included in the analysis.
- The justification for ToRc was the need to first flag emerging issues identified by the various participants for WGAQUA to effectively address relevant issues and provide timely science advice to promote the sustainable use of living marine resources and the protection of the marine environment. The aim was to identify and rank issues identified by the group as a whole that may require future attention by the WGAQUA or other related ICES Expert Groups, either alone or through collaborative work. Specifically the task is to highlight new and important issues that may require additional attention by the WGAQUA and/or another Expert Group as opposed to providing a comprehensive analysis. During the inaugural meeting of WGAQUA ToR's a and b) were set up to summarize the reports, recommendations and advice given on Aquaculture related topics

by other working and study groups within ICES over the last decade (such as WGEIM, WGMASC, WGAGFM, WGPDMO, WGICZM, WGITMO and SGSA). On the basis of this knowledge ToR c) should focus on the emerging issues as identified by the various participants during the meeting. After an initial broad and open ended discussion the list contained topics both relevant to WGAQUA and other working and study groups within ICES. The various suggested emerging topics were compared to the reports, recommendations and advice of earlier groups and there is a relative large overlap. This signifies that some of the topics while maybe not new or emerging they still stand as unresolved and central. The topics relevant to WGAQUA are listed below in table I (Annex 4) and the topics we deem more thematically suited for other groups of ICES are summarized in Table II (Annex 4). Additional information was sought in European agencies and interest groups such as EFARO, EATiP, AquaMEd and others. EATiP had recently done a similar exercise and they had chosen to divide their topics into 8 thematic groups. To compare the two exercises we have assigned the topics defined by WGAQUA to one of the thematic groups of EATiP. Eight new ToRs were identified and grouped under three themes. Given the size of the group and the diverse topics to be addressed, theme leaders were identified to aid in the development and reporting of ToR activities and to ensure linkage are made between ToR activities:

- Theme 1: Benthic Effects (Raymond Bannister)
- Theme 2: Pest Management (Dave Jackson)
- Theme 3: Ecosystem Interactions (Chris McKindsey)
- Discuss chairs for WGAQUA and possible new EGs. The three Chairs were approved by the meeting participants for the next two years (Pauline Karmermans – shellfish and macroalgae, Karin Boxaspen – finfish and Peter Cranford – science advice). The possible development of subsidiary expert groups reporting to WGAQUA was discussed. Possible additional expert groups could be developed under the following topics identified in the ICES aquaculture discussion paper:
  - Economic and ecological efficiency
  - Management tools to ensure sustainability
  - Interactions with natural environment and fisheries

An additional subsidiary group that would greatly benefit the activities of WGAQUA is the Study Group on Socio-Economic Dimensions of Aquaculture. While the possibility of having ICES expert groups reporting to WGAQUA remains open for discussion with SCICOM, the current WGAQUA structure focused on addressing common ToR theme areas during the present reporting cycle under the sub-leadership of WGAQUA members.

- Cooperation with other WG
  - Science advice on aquaculture usually includes not only ecological and technical, but also socio-economic aspects. The present membership does not include experts with a socio-economic background. SGSA was created specifically to deal with these issues. Therefore, WGAQUA recommends SGSA to be invited to join WGAQUA.
- Cooperation with Advisory structures

- It is recommended that that ACOM initiate the process of drafting specific advice questions for presentation to WGAQUA members at the 2014 annual meeting. The Science Advice chair is available to participate as required in developing these questions and for ensuring a timely response by WGAQUA to each query.
- Science Highlights
  - Since the nature of the meeting was mostly planning and discussing topics to work on in the new EG, no science highlights can be reported in Year 1.

## 6 Revisions to the work plan and justification

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The new ToRs to be worked on in Year 2 and Year 3 are listed below under each current WGAQUA theme. ToR leaders are also indicated along with ToR justifications. Development of a full list of ToRs was part of the WGAQUA workplan for 2013 given that this is a new expert group.

### 6.1 Benthic Effects Theme led by Raymond Bannister (Norway):

- d) Identify and assess approaches for analysing the effects of aquaculture on benthic habitats with a focus on rocky and mixed substrata bottoms. Recommend approaches to assess/monitor these habitats (*Raymond Bannister*)

**Justification:** Development and establishment of monitoring methodology/tools for detecting/evaluating environmental impacts of aquaculture to marine ecosystems has been a topic of considerable interest for traditional cultivation locations over the past two decades. However, most of this work has concentrated on soft substratum habitats. The gradual relocation of aquaculture facilities to deeper localities dominated by hard and mixed substrata habitats has resulted in problems with using these established monitoring tools. Therefore, there is an urgent need to establish standardized monitoring methodology/tools for hard bottom and/or mixed bottom habitats being exploited through aquaculture operations to improve sustainability.

- e) Identify and assess approaches for analysing the interactions between aquaculture and eelgrass and maerl beds. Recommend approaches to assess/monitor these habitats (*Pauline Kamermans*)

**Justification:** Development and establishment of monitoring methodology/tools for detecting/evaluating environmental impacts of aquaculture to marine ecosystems has been a topic of considerable interest for traditional cultivation locations over the past two decades. However, most of this work has concentrated on soft substratum habitats. Aquaculture sites are also being established in more coastal areas, at times in areas with seagrasses, maerl beds, and other sensitive habitats. Therefore, there is an urgent need to establish standardized monitoring methodology/tools for seagrass and maerl beds being exploited through aquaculture operations to improve sustainability.

### 6.2 Pest Management Theme led by Dave Jackson (Ireland):

- f) Analyse and assess the environmental effects of biofouling pest management in aquaculture with an emphasis on i) chemical release, ii) benthic organic enrichment, iii) waste management, and iv) propagule pressure. Ultimately, a risk assessment framework will be developed with respect to treatments for bivalve aquaculture pests within a greater pest management framework. (*Thomas Landry*)

**Justification:** The management of pest species in bivalve aquaculture has received increased attention in the recent past, particularly in reference to tunicate management in mussel farming. The development of treatment regimes and methods has been mainly focused on the efficiency of control methods and therapeutants. To manage tunicates in bivalve farms, farmers may apply a variety of chemical products (e.g. lime, vinegar) to product and/or equipment or use physical methods to remove/kill fouling tunicates. In bivalve cul-

ture, mechanical methods of tunicate removal may greatly augment the deposition of organic matter (dead and dying tunicates and other fouling species and product) to the seabed within and around culture sites. The process may also encourage the liberation of propagules (larvae or fragments of colonial species) that may hasten the spread of invasive species. To date, little work has addressed these issues. Moreover, the risk associated with the various aspects of pest management has not been evaluated within a structured format such that decisions relating to treatment options are commonly made without regard to other possibilities. Greater certainty associated with the risks surrounding various aspects of pest management will support decisions relating to various treatment options

- g) Analyse and assess the environmental effects of sea lice pest management in aquaculture with an emphasis on i) therapeutant release, ii) waste management, and iii) propagule pressure. (*Karin Boxaspen and Dave Jackson*)

**Justification:** The management of pest species in finfish mariculture has received increased attention in the recent past, particularly in reference to sea lice management in salmon farms. The development of treatment regimes and methods has been mainly focused on the efficiency of control methods and therapeutants. To manage sea lice levels at marine cage finfish sites, aquaculture operators rely upon a number of therapeutant treatment products. These products are delivered either in-feed (e.g. SLICE® active ingredient: emamectin benzoate) or topically through bath treatment (e.g. Alphamax™, active ingredient: deltamethrin). The active ingredients in therapeutants, regardless of their mode of application, may enter the aquatic environment through a variety of pathways (e.g. dissolution, particle transport and sedimentation) and thus may reside in the water column or accumulate in benthic ecosystems and expose non-target organisms. To date, little work has addressed these issues. Moreover, the risk associated with the various aspects of pest management has not been evaluated within a structured format such that decisions relating to treatment options are commonly made without regard to other possibilities. Greater certainty associated with the risks surrounding various aspects of pest management will support decisions relating to various treatment options

### 6.3 Ecosystem Interactions Theme led by Chris McKindsey (Canada):

- h) Assess and analyse issues relating to the attraction and repulsion of wild populations by fish and shellfish farms and of the impact of this on these populations and the individuals (*Chris Mckindsey*)

**Justification:** An increasing number of studies have shown that the presence of an aquaculture farm may affect wild fish and other species in a given area. Fish farms may attract wild fish because of feed and other waste products associated with farms, altered communities associated with farms, and the physical structure of farms, which may offer alternate refuges or food sources. In contrast, anecdotal evidence suggests that some fish have altered their spawning and migratory behaviour to avoid areas with farms. With respect to the attraction of fish to farms, their consumption of waste products may alter the quality of the fish (size, condition, texture, flavour, etc.). It is largely unknown how any of these factors differ at different life stages.

- i) Analyse and assess the potential ecosystem services and impacts of aquaculture, including extractive aquaculture approaches for environmental impact biomitigation (*Myriam Callier, Peter Cranford, Jens Petersen*)

**Justification:** The environmental interactions of mariculture are receiving more attention with respect to the negative impacts of the industry, despite the growing information on the ecosystem services that this activity can provide. Well managed mariculture generally increases the net production of its host environment by maximizing the use of natural resources, from a physical, chemical and biological perspective. Nutrient trading or bio-extraction as a mitigation measure for coastal eutrophication is a relatively new topic that is gaining considerable support from different industries and regulators. It entails trades between companies discharging excess nutrients to coastal waters and aquaculture farms that produce shellfish that can help to moderate phytoplankton concentrations and act as a nutrient sink when harvested. In addition, Integrated Multi-Trophic Aquaculture (IMTA) strives to achieve a balance between commercial production and environmental sustainability by using a natural recycling concept where the by-products from one species become inputs for another within the same culture system. Commercial scale open-water IMTA operations are being developed to reduce organic enrichment impacts in some areas. Bivalves and other economically valuable macroinvertebrates, such as sea urchins, sea cucumbers and worms, have been evaluated as components of IMTA systems and have attracted considerable industry interest. However, there are still unresolved questions regarding these extractive aquaculture approaches such as: how efficient are they (i.e. to what extent do shellfish act as nutrient sinks relative to the nutrient supplies and how much fish waste can be extracted by shellfish and other species)? It is also important to balance the positive effect of the nutrient removal in the harvest with the potential negative effects of nutrient retention in the coastal zone that may occur as a result of the biodeposition activities of the introduced extractive species. The economic aspects in relation to nutrient trading quotas and species diversification at IMTA farms need to be evaluated. Outstanding issues exist with the integration of ocean ranching of echinoderms with fish culture and include interactions with wild stocks (and fisheries), the potential impacts (displacement?) of existing habitat, and the required ranching densities needed to offset the waste fluxes. WGAQUA will review efforts worldwide and report on the subject. As a first step, a background paper will be produced outlining the general issues and the negative and positive endpoints of mariculture and extractive aquaculture.

- j) Assess the knowledge base on acceptance of aquaculture in Marine Protected Areas (*Adele Boyd*)

**Justification:** The implementation of Marine Protected Areas (MPAs) can cause restrictions for fish and shellfish-farmers and conflicts between aquaculture producers and environmental authorities. Spatial planning can help in these issues. However, this is rarely a joint process of all stakeholders. The fact that the definition of an MPA is not clear contributes to that. Furthermore, the benefits of MPA's to aquaculture (i.e ecosystem services) are often not communicated. For example, shellfish produced in an MPA might provide a better image of sustainable aquaculture practices. The WGAQUA will review guidelines such as Natura 2000, and compare the implementation in different ICES countries, identify differences between different types of MPAs and identify

different management strategies. In addition potential gaps between ambition and reality will be identified, and knowledge of the impact of shellfish aquaculture in different countries will be evaluated. WGAQUA can provide science-based recommendations on such topics as criteria and thresholds for management decisions, an evaluation of present management regimes, and how to deal with the lack of baseline information.

- k ) Characterize risks, real and perceived, and potential ecological benefits associated with introducing foreign strains and species of finfish and shellfish and other invertebrates for aquaculture purposes (*Thomas Landry and Gef Flimlin*)

**Justification:** Aquaculture companies have, and will continue to seek access to better performing aquaculture strains, however, concerns centering on the potential ecological impacts of such introductions on local wild populations often prevents transfer requests from being granted. Characterization of risks involved with introducing foreign species of organisms or domesticized strains for aquaculture purposes would help inform policy development and decision-makers and help to reduce conflict between aquaculture operators, regulators and other interested members of the public (traditional fishers, NGOs, etc.). There have been many published studies that have researched interactions between cultured and wild salmonids (for both aquaculture and enhancement efforts), effects of these interactions include growth and survival, reproductive interactions between wild and cultured fish, and escape mitigation. Likely a similar body of work exists for shellfish. It would be beneficial to consolidate the body of work to provide advice on the potential/perceived risks of introducing strains for culture. A review of measures to reduce or mitigate these risks would be valuable to help inform policy development and decision-makers and reduce conflict between aquaculture operators, regulators and other interested members of the public (traditional fisheries, NGOs, etc.)

#### 6.4 Summary of the workplan:

##### Year 2

ToR leaders will prepare an outline of each ToR report (potential publication) intersessionally and will present that at the meeting. WGAQUA members will work on ToRs c-k during the meeting depending on attendance (number of people and their expertise).

Evaluate Outreach/PR activities and develop outreach plan for Year 3.

##### Year 3

ToR leaders prepare outline of publication intersessionally and present that at meeting. During meeting finalize products depending on attendance (number of people and their expertise).

Discuss future of group.

Formal advisory activities of WGAQUA are considered separate from ToR activities and not subject to the same 3-year reporting cycle. Any formal advisory requests received by the Science Advice Chair from ACOM will be distributed to members intersessionally and a workplan developed at the next annual meeting. Advisory



reports generated by identified experts within the group will be peer-reviewed by all WGAQUA members at annual meetings and a final consensus report, including any dissenting opinions, will be provided to ACOM.

## **7 Next meeting**

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The next meeting will be held in Spain (probably Vigo) 31 March to 4 April 2014.

## Annex 1: List of participants

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## Annex 2: Recommendations

Recommendation	Adressed to
1. Member states (Norway in particular, 2011) have asked if ICES can give advice related to the sustainability of aquaculture (finfish in particular). WGAQUA was formed, in part, to facilitate the provision of science advice on aquaculture issues and to attract a broad mix of finfish, shellfish and macroalgal aquaculture scientists. The membership of WGAQUA currently stands at 45 scientists from 14 ICES member states. A Science Advice co-chair has been tasked specifically with coordinating group responses to formal advisory requests. WGAQUA recommends that ACOM initiate the process of drafting specific advice questions for presentation to WGAQUA members at the 2014 annual meeting. The Science Advice chair is available to participate as required in developing these questions and for ensuring a timely response by WGAQUA to each query.	ACOM
2. WGAQUA recommends that ACOM provide direction to the group on protocols adopted by ICES for preparing and reporting science advice (e.g. OSPAR requests, fisheries assessments). Alternatively, provide approval for WGAQUA to develop protocols for addressing aquaculture advisory requests.	ACOM
3. WGAQUA proposes a Theme Session for the 2014 Annual Science Conference on The application of science for ecosystem-based management of aquaculture.	SCICOM
4. WGAQUA recommends that ICES contact delegates to seek additional representation on WGAQUA for experts on macroalgae aquaculture as well as to seek members from r ICES states that are currently not represented in the group. Recommend SGSA members be invited to join WGAQUA as a ToR theme or as a subsidiary expert group to increase expertise and to aid in the drafting and provision of science advice.	SCICOM, SGSA, Delegates
5. It is recommended that WGAQUA accept the invitation to participate in the work and deliberation of ISO TC 234 as a liaison organization (Level B). Participation by the chair(s) requires funding under SCICOM (or ACOM) as well as additional information on the perceived role of WGAQUA in this activity.	SCICOM, SSGHIE

### **Annex 3: Synthesis of reports and recommendations by ICES SGs and WGs related to sustainable aquaculture**

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## 1 Overview of ICES Expert Group Activities Related to Aquaculture.

The work of WGAQUA on ToR a and b both included reviewing the contents of past ICES expert group reports to extract and synthesize information that may be relevant to the WGAQUA workplan. This exercise was also conducted to avoid overlap between expert group activities, to assist in linking topics of common interest, to integrate work products, and to communicate outputs across ICES expert groups. Annual reports generated between 2003 and 2012 by the SGSA, WGAGFM, WGEIM, WGICZM, WGITMO, WGMASC, WGPCZM and WGPDMO were divided among WGAQUA members with the task of identifying and summarizing topics addressed related to;

- 1 ) the environmental dependence and effects of aquaculture (ToRa), and
- 2 ) advise and recommendations related to sustainable aquaculture (ToRb).

In order to demonstrate and maintain the close linkages between the science and advisory activities of these ICES expert groups, ToR a and b overviews were addressed and reported concurrently.

The WGEIM and WGMASC ToRs were dedicated to aquaculture and these groups were combined to form WGAQUA. Consequently, their tasks and outputs are well known within WGAQUA and only their publications are listed along with a summary of topics in tabularised form. For these groups, our focus was on reviewing their advisory activities. Additional working group activities (e.g. WGHABD and WGEKO) are also relevant but had been reviewed previously as part of activities conducted by the WGEIM, WGMASC and WGICZM.

### 1.1 ICES Working Group on Introduction and Transfers of Marine Organisms (WGITMO)

Table 1.1. Aquaculture related topics from the ICES Working Group on Introduction and Transfers of Marine Organisms (WGITMO)

Topic	2007	2008	2009	2010	2011	2012
1	Identify and report on changes in the distribution, population abundance and condition of introduced marine species					
2	Develop Alien Species Alert report, including evaluation of impacts, and to increase public awareness on the Pacific oyster <i>Crassostrea gigas</i> .					
3	Development of criteria for the creation of high-low risk species lists					



### 1.1.1 Summary of WGITMO outputs on aquaculture topics.

2007:

- *Crassostrea gigas* was introduced as aquaculture but has since become established and is spreading throughout Europe. Species range expansions are not well documented as responses to temperature, salinity, and/or other climate change impacts. There is some evidence that changes in the rates of reproduction are related to warmer temperatures. Proposed to review the current status of knowledge concerning the *Crassostrea gigas* invasiveness. WGITMO suggests preparing intersessionally a Species Alert Report on the Pacific oyster *Crassostrea gigas* with the aim to finalize the report in 2008.

2008:

- Discussed the IMPASSE Risk Assessment Scheme which provides protocols for assessing the risks of using alien species in aquaculture'. This is the scheme to be used in Europe for compliance with the new EU Regulation of the use of alien species in aquaculture. The current UK scheme was used as an example to assess the Pacific oyster *Crassostrea gigas*, which was introduced to Europe in 16th century (Portugal), and then again in 1960s and 1970s. The species is now farmed in large part in France, and it is spreading along European coasts. The assessments were carried with currently uninfested areas of the Normandy and UK coasts as the risk assessment areas. For the initial, hazard identification, phase of these assessments, the marine invertebrate invasiveness scoring kit (MI-ISK) was used to assess invasive-ness potential ([www.cefas.co.uk/4200.aspx](http://www.cefas.co.uk/4200.aspx)). The outcomes of these assessments were largely similar, with both resulting in 'high risk' MI-ISK scores, with medium-to-high impact ratings and medium uncertainty levels using the UK scheme.

2009:

- WGITMO agreed that the current approach for evaluating national reports on the spread of invasive species was not effective.

2010:

- One aquaculture release was reported by the US Adults of the shrimp *Penaeus monodon* were observed off the coast of North Carolina, but no reproducing populations were found. This is the northern-most sighting for this species which is from Guyana. *Crassostrea gigas* is also an aquaculture escapee and is reported as range expansion in Ireland.
- Provided information on regulations concerning use of non-native species in aquaculture. The regulations include a rank of Low risk for species that have been in aquaculture for a long time and have no reported impacts. High risk considers species problematic unless proven otherwise. Screening is required to determine if high risk. The issue of what to do with the medium risk remains the conundrum. The European Union needs to consider other EU states' concerns about species they want to use in aquaculture. For example, EU document, Paragraph 6 – provides guidance on risk assessment and notes the community should develop own framework but in the short excerpt there is no mention of ICES Code of Practices and risk assessment guidelines. In the EU regulations, veto power of neighbouring states is not addressed.

2011:

- Problem species in the Netherlands are the oyster drills *Urosalpinx cinerea* and *Ocenebrellus inornatus*. The expansion of *Ensis directus* and *Crassostrea gigas* continued. Both are dominating the benthic community in the Dutch coastal waters. The Pacific oyster (*Crassostrea gigas*) has suffered substantial set-back on studied localities (harsh winter) in SE Norway.
- The Council Regulation (EC) No 708/2007 concerning use of alien and locally absent species in aquaculture was considered. It was suggested that the generic ICES Code of Practice definition of risk should be left as it is currently defined. It was proposed that the ICES CoP be revised to make it clear that the Risk Assessment is only the first step, and explain the roles of different groups involved in the decision-making.

2012:

- Important persistent aquatic invasive species in Atlantic Canada are green crab (*Carcinus maenas*) and tunicate species. These are also considered as new and future aquatic invasive species within this region as these organisms are spreading from one Atlantic province to the next.

#### 1.1.2 Summary of WGITMO advice/recommendations on aquaculture topics:

2007:

- The aquaculture industry should find the information in the National Reports on parasites, pathogens and other disease organisms useful, and but it is uncertain that they are receiving the information.

2008:

- Risk Assessment approaches continue to evolve and will be a topic for continued updates for WGITMO. WGITMO recommends that wild and aquaculture *C. gigas* populations be discussed in the report.

2009:

- Evaluating national reports on the spread of invasive species:
  - The group should focus on creating a set of data using sources other than the national reports that can then be compiled into a report looking at invasion status and trends, as was done for the earlier algae and higher plant sections. This type of report could also be used to start looking at effects that are expected as a result of climate change and to compile all the information the group has on vectors.
  - Another suggestion was to build on the current excel spreadsheets that are submitted with the national reports to build a solid AIS dataset within the ICES statistical database. It was not clear if this option was technically feasible, nor was it clear how to include information from countries that are not reporting annually.
  - It was decided that only species which have at least part of their life cycle in the marine or brackish environments should be included in reports.
- The report on the status of *C. gigas* needs to be finalized

- Development of criteria for the creation of high-low risk species lists: It was recommended that because this is a complex issue that is not going to be resolved in 2009, the group should work intersessionally to describe the work that is already underway in many countries and to identify major issues of concern, such as genetics and climate change. This will be compiled into a white paper that will be sent to ICES for their review and consideration.

2010:

- From the ICES PICES Joint Meeting it was recommended to develop and share a database on marine invaders and taxonomic experts.

2011:

- Concerning the quality of the invasive species database, it was stated that an editorial board of the database is needed. It should consist of specialists having knowledge of regional seas and taxonomic group experts. The editorial board should oversee that species names in the database are valid, that species are identified correctly and that all species related attributes such as biological traits, environmental data, possible introduction vector, impacts and other information are all accurately indicated in the database. The rough estimate is that 15-20 persons per regional sea would be required.

2012:

- The ICES Code of Practice (CoP) on the Introductions and Transfers of Marine Organisms should be made available via ICES webpage.

### 1.1.3 References

- ICES. 2007. Report of the Working Group on Introductions and Transfers of Marine Organisms (WGITMO), 21–23 March 2007, Dubrovnik, Croatia. ICES CM 2007/ACME:05.160 pp.
- ICES. 2008. Report of the Working Group on Introduction and Transfers of Marine Organisms (WGITMO), 12–14 March 2008, Copenhagen, Denmark. ICES CM 2008/ACOM:52. 130 pp.
- ICES. 2009. Report of the Working Group on Introduction and Transfers of Marine Organisms (WGITMO), 11 - 13 March 2009, Washington D.C., USA. 220pp.
- ICES. 2010. Report of the ICES Working Group on Introductions and Transfers of Marine Organisms (WGITMO), 10 - 12 March 2010, Hamburg, Germany. ICES CM 2010/ACOM:29. 130 pp.
- ICES. 2011. Report of the Working Group on Introduction and Transfers of Marine Organisms (WGITMO), 16 - 18 March 2011, Nantes, France. ICES CM 2011/ACOM:29. 180 pp.
- ICES. 2012. Report of the ICES Working Group on Introduction and Transfers of Marine Organisms (WGITMO), 14 - 16 March 2012, Lisbon, Portugal. ICES CM 2012/ACOM:31. 301 pp.

## 1.2 ICES Working Groups on Integrated Coastal Zone Management (WGICZM) and WG on Marine Planning and Coastal Zone Management (WGMPCZM)

Table 1.2. Aquaculture related topics from the ICES Working Group on Integrated Coastal Zone Management (WGICZM), which became the WG on Marine Planning and Coastal Zone Management (WGMPCZM) in 2011.

Topic	2006	2007	2008	2009	2010	2011	2012
1	Development of a framework for integrated evaluation of human impacts in the coastal zone					Spatial planning tools to assist IM practitioners. Quality assurance in management plans	
2	Update and report on ICZM activities in different ICES Member Countries						
3	Update and report on activities of relevant ICES groups to identify information pertaining to coastal zone and evaluate this information relative to ICZM needs and review progress from the EU and IOC						
4	Standardized methods for indicator selection						
5				Evaluate the usefulness of assessing ecosystem goods and services in ICZM		Socio-economic understanding of ecosystem goods and services	
6						Application of IM to address interactions between commercially exploited species and natural systems including aquaculture	

### 1.2.1 Summary of WGICZM and WGMPCZM outputs on aquaculture topics.

2006:

- A specific role for ICES within a framework for integrated evaluation of human impacts in the coastal zone could be to deliver the baseline information and expertise to develop a model to assess the vulnerability of marine and coastal ecosystems to changes which relate to human activities. The next step would be to integrate the vulnerability assessment with risks associated to human activities. Human demands for coastal and ma-

rine space and resource use including Coastal Zone Conflict could be organized in the following manner:

- Identification of human activities such as urbanization, tourism, aquaculture, energy production or other uses;
- Their interactions with coastal and marine ecosystem processes;
- The risk associated with these activities to create a severe impact on ecosystem functions (e.g. risks from oil spills, pollution,...);
- Problems that may arise such as xenobiotic organisms introduced directly or indirectly by human activities.

2007:

- Provided an Annex (#5) summarizing key issues, impacts and information gaps related to mariculture and coastal ecosystems as identified by other working groups.
- Provided an Annex (#6) identifying ICES Member Countries where aquaculture is a key activity, the relevant ICZM legislation and the presence of ICZM projects and management initiatives.

2008:

- Identified the need for integrated decision-making frameworks as opposed to standardized lists of indicators and the necessity of specified management objectives at an appropriate scale. Noted that it is not feasible to apply a single list of indicators to all monitoring programmes. Nevertheless, it was proposed that coherent and coordinated methods of selecting and implementing indicators, selecting comparable measures wherever applicable were essential.

2009:

- Evaluating ecosystem goods and services, particularly in economic terms, is a valuable way of communicating the importance of environmental sustainability to the public. It is important to recognize that there are many non-market values that should be assigned to ecosystem goods and services (i.e. social, cultural, existence, intrinsic, spiritual, option). Assigning a tangible value to ecosystem goods and services, which can be approached from many disciplinary perspectives, facilitates discussion and evaluation of management actions that are based on quantifiable costs and benefits.

2010:

- Most ICES countries still have fragmented responsibilities for legislation and policies among authorities, and a lack of a legal framework to support ICZM nationally and internationally. This raises concern over the lack of compatibility among legislations at the national and ecoregion (ICES) levels and the inefficient collection, communication, dissemination, and compatibility of available datasets. It has also become clear that many of the key issues facing decision-makers in the coastal zone are localized and therefore require a local solution.
- Outlines the COEXIST, AQUA REG and ECASA projects that deal with the sustainable development of aquaculture and related tools.
- Outlines key issues for ICZM in several countries (Germany, Norway and the UK) related to aquaculture activities.

2011:

- Examples of aquaculture marine spatial planning (MPS) noted during discussions of large-scale MSP development and guidelines for best-practice.

2012:

- The challenge of MSP is to allocate sea space in line with the ecosystem approach and in a way that achieves an acceptable distribution of risks and opportunities to the communities and economies affected. This leads to three requirements: a) to get to know the resource (ecology, different sea values, goods and services), b) to establish risks that new uses or cumulative impacts might bring to the resource and to goods and services, and based on these, c) to set priorities for MSP and/or management.
- For MSP, a key concern is to develop methods for identifying cultural values and for mapping those areas that are of particular importance for cultural reasons.
- Identified three main topics important for quality assurance: 1) Unbiased scientific peer review process of management advice, 2) QA in terms of governance; setting objectives, regulatory process etc. 3) QA in relation to environmental effects monitoring, regulatory decision-making and verification and auditing of environmental management plans.

### **1.2.2 Summary of WGICZM and WGMPCZM advice/recommendations on aquaculture topics:**

2006:

- WGICZM recommends that ICES works to develop a model to assess the vulnerability of marine and coastal ecosystems to changes which relate to human activities. Having progressed this far, the next step is to integrate the vulnerability assessment with risks associated to human activities.
- WGICZM further recommends that ICES continues to:
  - develop ecological quality objectives and indicators on environmental quality in coastal- and transitional waters;
  - establishes reference conditions/values, assesses interplay between natural variability and cycles and pressure due to human activities;
  - further examines the effects of changes in climate for the coastal zone;
  - Revisits the categorization of coastal water, transitional waters and heavily modified water bodies done by different EU-countries;
  - Examines how to tackle cross-boundary pressures, for example long-distance transport of nutrients and pollutants, shipping;
  - Defines scientific based limits for high, good and moderate ecological status;
  - Advices on monitoring and surveillance programmes and methods for coastal monitoring; Promotes comparative studies, inter-calibration exercises and a sound scientific basis for the implementation of the WFD; and

- Considers potential and realism in enterprises and measures to improve ecological status in coastal- and transitional water.

2007:

- ICES continues to develop ecological quality objectives and environmental quality indicators in coastal and transitional waters.

2008:

- The WGICZM recommends continuing to update and report on activities of relevant ICES working and studying groups to identify information pertaining to the coastal zone and evaluate this information relative to ICZM needs and to monitor progress within the EU and IOC.
- It was recommended that the WGICZM work towards:
  - Bringing together the risk characterization and the indicator characterization approaches within an integrated decision-making framework.
  - Developing a general framework for the indicator selection process for ICES countries. Within that framework should be the clear definition of objectives and the integration of the indicator system into the overall management process.
  - Exploring the possibility of putting together a proposal developing the integrated decision-making framework for ICZM.

2009:

- ICES promote the adoption of a harmonized, structured decision-making framework for ICES Member States. By continuing to monitor existing and emerging decision-making tools and frameworks, WGICZM will be able to contribute to this recommendation and provide advice to ICES
- The process of assessing ecosystem goods and services can provide valuable contributions to the decision-making process but should be used in conjunction with other tools. It is recommended ICES take the position that the assessment of ecosystem goods and services should be based on strong sustainability principles.

2012:

- An ICES Cooperative Research Report (CRR) on Risk Analysis (RA) Framework was prepared with procedures for risk management in mind and adopting ISO language of risk management. It highlights key tools and a sequence of steps involved in RA.

### 1.2.3 References

- ICES. 2006. Report of the Working Group on Integrated Coastal Zone Management (WGICZM), 19–21 April 2006, ICES Headquarters, Copenhagen. ICES CM 2006/MHC:08.107 pp.
- ICES. 2007. Report of the Working Group on Integrated Coastal Zone Management (WGICZM), 17–20 April 2007, . CM 2007/MHC:09. 69 pp.
- ICES. 2008. Report of the Working Group on Integrated Coastal Zone Management (WGICZM), 11–14 March 2008, Mallorca, Spain. ICES CM 2008/MHC:05. 111 pp.

- ICES. 2009. Report of the Working Group on Integrated Coastal Zone Management (WGICZM), 24–27 March 2009, GKSS Research Centre, Geesthacht, Germany. ICES CM 2009/MHC:06. 89pp.
- ICES. 2010. Report of the Working Group on Integrated Coastal Zone Management (WGICZM), 9–12 March 2010, Mallorca, Spain. ICES CM 2010 / SSGHIE:05. 69 pp.
- ICES. 2012. Report of the Working Group for Marine Planning and Coastal Zone Management (WGMP CZM), 20–23 March 2012, ICES Headquarters, Copenhagen, Denmark. ICES CM 2012/SSGEF:07. 91 pp.



### 1.3 ICES Study Group on Socio-Economic Dimensions of Aquaculture (SGSA)

Table 1.3. Aquaculture related topics from the ICES Study Group on Socio-Economic Dimensions of Aquaculture (SGSA)

Topic	2011	2012
1	Methods to assess the direct and indirect socio-economic consequences of the use of marine space by aquaculture	
2	Identifying and strengthening local stakeholder inclusion and local ownership in the aquaculture production chain	Examine how inclusion and local ownership influence aquaculture
3	Address how social values and administrative organizations in different countries/regions affect trends in the intensity, methodology, acceptance, structure and type of aquaculture	
4	Identify new emerging issues of socio-economic aspects of aquaculture	
5		Identify how social, economic, governance and environmental framing conditions influence aquaculture development

#### 1.3.1 Summary of SGSA outputs on aquaculture topics.

2011:

- A clear definition of socio-economic and ecological objectives for all aquaculture operations is necessary which acknowledge the social, economic and ecological dimensions.
- A stronger consideration of the distribution of benefits (related to inputs and outputs) throughout the social-ecological system is recommended (who is benefiting and to what extent).
- Significant progress has been made towards evaluating the socio-economic and, perhaps even more, the ecological impacts of aquaculture, although less progress has been made towards utilizing this information to influence management decisions. The SGSA has developed a preliminary framework for an integrated assessment of the socio-economic dimensions of aquaculture.
- Many aquaculture assessments focus primarily on the impacts of the activity without enough consideration of the framing conditions that are driving those impacts or that influence how the impacts are managed. Understanding the local context (social, political, environmental, economic) is critical to the effective evaluation and management of aquaculture scenarios.

2012:

- Identified a preliminary list of methods, which could support an integrative assessment within a social-ecological framework.

- Need to establish knowledge bases for decision-making via stakeholder inclusion, for example through an environmental or social impact assessment. Include stakeholders and their supporting values in the decision-making process.
- Need to carry out a systematic identification of framing conditions (Understanding the local context) of aquaculture as a key step towards informing management measures that will allow aquaculture to realize its full potential. Tools for the assessment of these framing conditions need to be identified.
- The socio-economic implications of certification schemes were flagged as a key emerging issue.

### **1.3.2 Summary of SGSA advice/recommendations on aquaculture topics:**

2011:

- There should be an explicit acknowledgement of the complex, interrelated social, economic and ecological dimensions of aquaculture operations. These pertain to direct and indirect impacts but also to the socio-economic and environmental framing conditions under which aquaculture projects are developed and implemented.
- Any detailed analysis of the inputs and outputs of aquaculture should include an assessment of the spatial scales at which the variables act and the distribution of benefits (related to inputs and outputs).
- It was recommended to develop/review a methodological framework and tools for the assessment of socio-economic framing conditions. Potentially amenable tools include Rapid Rural Appraisal (RRA), Sustainable Livelihoods Approach (SLA) and New Institutional Economics (NIE). The SGSA recommends that future research related to aquaculture should place more emphasis on these dimensions 2012:

2012:

- Understanding the local context (social, political, environmental, economic) is critical to the effective evaluation and management of aquaculture scenarios. This is especially pertinent with respect to socio-economic framing conditions which are often overlooked in scientific studies. The role of framing conditions must be stronger emphasis in future research
- Include stakeholders and their supporting values in the decision-making process.

### **1.3.3 References**

- ICES. 2011. Report of the Study Group on Socio-Economic Dimensions of Aquaculture (SGSA), 12–14 April 2011, Bremen, Germany. ICES CM 2011/SSGHIE:11. 31 pp.
- ICES. 2012. Report of the Study Group on Socio-Economic Dimensions of Aquaculture (SGSA), 24–26 April 2012, Stockholm, Sweden. ICES CM 2012/SSGHIE:10. 41 pp.

## 1.4 ICES Working Group on Marine Shellfish Culture (WGMASC)

Table 1.4. Aquaculture topics from the Working Group on Marine Shellfish Culture (WGMASC).

Topic	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
1	Hatchery impact on shellfish production, application of genetic tools and genetic consequences on natural populations									
2	Stress indicators to explain mortalities									
3	Ecological factors affecting shellfish production and performance indicators									
4	Sustainability of shellfish culture									
5	Framework for the integrated evaluation of shellfish aquaculture impacts in the coastal zone									
6	Hatchery enhancement of wild fisheries									
7	Effect of bivalve aquaculture transfers between sites to wild and cultured bivalve stocks									
	Evidence of and effect of climate change on shellfish aquaculture distribution and production									
	Site selection criteria in molluscan aquaculture with particular reference to accessing and developing offshore facilities									

### 1.4.1 Summary of WGMASC publications on aquaculture topics.

Cranford PJ, Kamermans P, Krause G, Mazurié J, Buck B, Dolmer P, Fraser D, Gubbins M, Van Nieuwenhove K, O'Beirn FX, Sanchez-Mata A, Thorarinsdóttir GG, Strand Ø. 2012. An ecosystem-based approach and management framework for the integrated evaluation of bivalve aquaculture impacts. *Aquaculture Environmental Interactions* 2: 193-213.

Muehlbauer F., D. Fraser, M. Brenner, K. Van Nieuwenhove, M. Gubbins B. H. Buck, O. Strand, J. Mazurié, G. Thorarinsdottir, P. Dolmer, F. O'Beirn, A. Sanchez-Mata, P. Kamermans. Bivalve aquaculture transfers in Atlantic Europe. Part A: transfer activities and legal background, submitted to *Aquatic Living Resources*

Brenner M., D. Fraser, K. Van Nieuwenhove, F. O'Beirn, B. H. Buck, J. Mazurié, G. Thorarinsdottir, P. Dolmer, A. Sanchez-Mata, O. Strand, G. Flimlin, P. Kamermans. Bivalve aquaculture transfers in Atlantic Europe. Part B: environmental impacts of transfer activities, submitted to *Aquatic Living Resources*

### 1.4.2 Summary of WG advice/recommendations on aquaculture topics by topic:

- 1) Hatchery impact on shellfish production, application of genetic tools and genetic consequences on natural populations
  - Develop hatchery registration and a national survey on shellfish hatchery production
  - WGITMO should monitor the implementation of the Code of Practice on the Introductions and Transfers of Marine Organisms for hatchery produced shellfish
- 2) Stress indicators in shellfish to explain mortality events
  - a) 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
  - b) An operational flowchart and set of working tables were developed to assess the types of mortality that a shellfish grower might encounter in the field and what may have caused these losses. This tool should be used by farmers and resource managers.
  - c) A monitoring system was also recommended to allow for early detection of problems and to provide a point of reference for future changes in shellfish production.
  - d) The diagnostic tool described in the ToR should be published and distributed to the farmers (e.g. through producer organizations) and the local managers in the languages of ICES countries. It is recommended, as a first step, that an ICES Cooperative Research Report be prepared on this topic. This report would be available to farmers, resource management and scientists and would serve as the foundation for additional discussion among experts and input from stakeholders that could lead to preparation of regional leaflets by responsible authorities.
- 3) Review of ecological factors affecting shellfish production, develop performance indicators
  - a) A comparative study of different management systems should be carried out with a view to identifying and testing the response of indices under different production conditions and management regimes. The goal will be to identify the key indices
  - b) Stakeholders should be consulted on the development of carrying capacity models so as to provide valuable input into potential constraints and assessing the value of selected performance indicators. The stakeholders should include industry members/representatives, conservation interests, regulatory representatives, and academia
- 4) Sustainability of shellfish culture
  - a) Sustainability was defined by the working group as: “the husbandry and future development of cultured shellfish stocks without compromising the structure and function of the ecosystem”. The WGMASC cannot state what impacts are acceptable. There

are valid socio-economic aspects to the sustainability question that cannot be addressed by scientists alone. Major roles of science are to advise on the potential consequences associated with aquaculture interactions with the environment, and to make recommendations towards the development of approaches for managing cultured shellfish stocks in a sustainable manner. Given the direct relation known to exist between the financial sustainability of the shellfish aquaculture industry and the ecological sustainability of coastal systems, environmental considerations need to be incorporated within management and development plans for shellfish aquaculture.

- 5) Framework for the integrated evaluation of the impacts of shellfish aquaculture activities in the coastal zone
  - a) EAA be based on a tiered environmental monitoring approach that is structured on the principle that increased environmental risk requires an increase in monitoring effort.
  - b) Local benthic geochemical and community parameters, while useful for site-specific environmental monitoring, are of limited value as indicators of changes at the ecosystem level. Some combination of modelling and measurement of selected far-field indicators related to benthic and pelagic communities, suspended particle depletion, shellfish performance is needed over relatively large (inlet-scale) areas to adequately assess the ecosystem level impacts of shellfish culture.
  - c) Regulatory decisions be based on partitioning the range of variation of an indicator into more than two classes/categories (acceptable vs. unacceptable). A few more threshold classes permits implementation of mitigation measures prior to reaching an unacceptable ecological state.
  - d) The introduction of the Marine Strategy and Water Framework Directives (also Canadian Oceans Act) mandates a DPSIR-type EAA approach that links ecological and socio-economic systems. It is therefore essential that the development of a management framework should be inclusive with diverse stakeholder participation, transparency and communication.
- 6) Hatchery enhancement of wild fisheries
  - a) The integration of aquaculture and fisheries management techniques in order to enhance scallop production. Industry, policy-makers and scientists act to assess the benefits of such methodology and facilitate plans for their use.
  - b) Further genetic studies on scallop populations be undertaken to determine whether geographic-based genetic population structuring exists, which could influence future wild stock management regulations.
- 7) Bivalve aquaculture transfers between sites to wild and cultured bivalve stocks

- a) Moving shellfish within and between countries and ecosystems, poses a high risk of ecological impact, to genetic integrity and to the introduction and spread of invasive species and pathogenic agents. There should be a presumption against routine introductions and transfers of molluscan shellfish; these should only occur through necessity, e.g. in the promotion of free trade and only be made following a full risk assessment to demonstrate negligible risk. As global communication continues to develop it becomes increasingly important to develop a more dynamic and transparent global approach.
- b) All possible alternatives at a local scale should be investigated before consideration of introductions as a last resort, e.g. employing hatchery or spat collection methods rather than importation.
- c) Proper risk assessment should be undertaken, irrespective of cost, to ensure safety to ecosystems, as the long-term environmental and financial costs from introductions is unquantifiable in the long-term. Risk assessments should include possible effects of diseases (parasites, viruses and bacteria), genetical contamination and hitch hiking species.
- d) Consultation on applications should be vigorous, be universally applied and be objective; and there should be a presumption against them, unless good scientific evidence proves otherwise.
- e) Monitoring of translocation of spat inter and between countries should be implemented to minimize transfer related risks and minimize the impact of e.g. Germany who routinely imports mussels from Ireland and Denmark, with resultant concerns regarding speciation or the introduction of pests or diseases.
- f) There is a need to regularly review and update regulations to account for and minimize the potential impact of emerging environmental or disease issues.
- g) Consideration should also be given to the risk to native stocks from inter-breeding. The resultant progeny invading ecosystems possibly being infertile, creating an imbalance within an ecosystem. If not infertile they may replace indigenous stocks
- h) Conform to industry codes of practice and legislation; e.g. ensure that illegal transfers are not made and that certification procedures are kept
- i) Develop and maintain a biosecurity measures plan
- j) improve record keeping and make records available to official health experts;
- k) employ best management practices of husbandry and hygiene to maximize health, growth and site production, with minimum impact on neighbouring sites.
- l) Harmonize legislation: to ensure that existing and developing legislation is joined up in relation to its interpretation, understanding and implementation by all stakeholders;
- m) Improve dialogue with industry improve communication among farmers, scientists and policy-makers, e.g. by forum meetings;

- n) Apply enforcement more effectively; develop policy;
  - o) Best educate and implement biosecurity measures with industry, and scientists;
  - p) Develop and maintain a trusting open dialogue with industry;
  - q) Coordinate and develop legislation to maintain sustainability.
  - r) Financial consideration should be secondary to ecological impact, if a company wishes to profit from an introduction they should be prepared to undertake proper scientific assessment of risk as long-term impacts can be serious and wide ranging.
- 8) Evidence of and effect of climate change on shellfish aquaculture distribution and production
- a) There is a high probability that climate change and ocean acidification has already had and will continue to have consequences for the biogeographical distribution and productivity of cultured shellfish species that will alter their ecological roles and economic potential. Key interlinked global warming variables that can impact shellfish aquaculture include advection, vertical mixing, convection, turbulence, light, rainfall, freshwater run-off, evaporation, oxygen concentration, pH, salinity, and nutrient supply. Although the available studies reveal that some important culture species will be at increasing risk in the coming decades, research on the direct and indirect effects of climate change and ocean acidification on many species is largely in its infancy.
  - b) ICES should actively promote, as a high research priority, further studies on the effects of climate change and ocean acidification on commercially cultured shellfish species, and particularly their sensitive early life stages. Research priorities include 1) determine sensitivities to perturbations under ecologically relevant conditions; 2) identification of the cumulative effects of warming and acidification; 3) assess the capacity of key species to acclimate and/or genetically adapt to related modifications of their environment; 4) given that climate change scenarios vary across ICES countries, assess regional susceptibilities for aquaculture impacts and the socio-economic consequences; 5) development of decision-making processes for mitigation of shellfish aquaculture impacts and a proactive strategy for adaptation.
- 9) Site selection criteria in molluscan aquaculture with particular reference to accessing and developing offshore facilities
- a) WGMASC should initiate a focused effort to identify the best offshore production concepts,
  - b) Rethink the logistics in relation to processing and transport to the market;
  - c) In the next decade an increasing large numbers of marine wind-parks will be established in off shore areas. The windparks may potentially support a production of bivalves. WGMASC should initiate an analysis of the potential for bivalve aquaculture in

windparks. The analysis should focus on blue mussels, but also include other shellfish species.

#### **1.4.3 References**

- ICES. 2003. Report of the Working Group on Marine Shellfish Culture (WGMASC), 13–15 August 2003, Trondheim, Norway. ICES CM 2003/F:05. 50 pp.
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- ICES. 2009. Report of the Working Group on Marine Shellfish Culture (WGMASC), 7–9 April 2009, Bremerhaven, Germany. ICES CM 2009/MCC:02. 91 pp.
- ICES. 2010. Report of the Working Group on Marine Shellfish Culture (WGMASC), 29 March–2 April 2010, Galway, Ireland. ICES CM 2010/SSGHIE:07. 94 pp.
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## 1.5 ICES Working Group on Application of Genetics in Fisheries and Mariculture (WGAGFM)

Table 1.5. Aquaculture related topics from the ICES Working Group on Application of Genetics in Fisheries and Mariculture (WGAGFM).

Year	Topic
2006	Genetic basis of domestication processes in farmed fish and shellfish
	Genetic effects of the introgression of farmed Atlantic salmon on wild salmon populations
2007	Potential application of genomics in fisheries management and aquaculture genetic and spatial data analysis methods for resolving spatial boundaries of finfish and shellfish populations, and for gaining insight into the geographic and ecological factors controlling the development of population boundaries
2008	Current and future prospects of QTL-based studies in fisheries and aquaculture
2009	Update and insights from the EU project SALSEA-Merge on establishment of a large-scale genetic database for assigning individual to population of origin
2010	Pursuing the establishment of a meta-database cataloguing molecular data in the field of fish and shellfish population genetics
	interaction of marine escaped farmed finfish on wild fish populations at a local and regional scale, and specific aspects for reducing uncertainty in risk assessment
	potential for using parasites, microbes and viruses as “magnifying glass” for fish stock characterization
2012	use of adaptive SNPs and other adaptive markers for genetic identification of populations (breeding stocks)

### 1.5.1 Summary of WGAGFM advice/recommendations related to aquaculture topics:

- 1) Genetic basis of domestication processes in farmed fish and shellfish Hatchery impact on shellfish production, application of genetic tools and genetic consequences on natural populations.
  - To promote studies on unintentional natural selection to understand the process of domestication and more experiments demonstrating the change and the genetic basis of such traits
  - To genetically monitor hatching of fish/shellfish to be used for sea ranching, aquaculture based fisheries or restocking purposes and to carefully estimate unintentional selection occurring during captivity.
  - To be aware of the unintentional selection going on in the hatcheries, which can/may have implications/potential effect on the wild population or induce further domestication.
  - To engage in more research regarding gene expression analysis for further understanding the nature of the genetic changes associated with domestication.

- 2) Genetic effects of the introgression of farmed Atlantic salmon on wild salmon populations.
  - The Guidelines on Containment of Farm Salmon, developed by the North Atlantic Farming Industry and the North Atlantic Salmon Conservation Organization (NASCO) should be the minimum standard for the construction and operation of fish farms. Research into further improving both technological and operation standards should be undertaken.
  - Smolt rearing units should not outflow into salmon rivers (as already required in Norway).
  - Marine cages should not be situated within 30km of salmon rivers.
  - Where escapes occur, appropriate recovery plans and resources should be available for immediate deployment.
  - Further investigations in the use of triploids and other bioconfinement methods should be undertaken.
  - If it is intended to introduce sterile transgenic salmon in the industry in the future, research should be undertaken prior to permission being granted, to determine the ecological impact that such fish may have on wild populations.
  - Building of realistic working simulation models, which can be used to assess risks of direct genetic interactions, which can be used to identify research priorities.
  - Research into indirect genetic and ecological impacts associated with issues such as introduction disease and effects of density-dependent population dynamics.
  - Spatial and temporal studies.
- 3) Potential application of genomics in fisheries management and aquaculture genetic and spatial data analysis methods for resolving spatial boundaries of finfish and shellfish.
  - The implementation of genomic approaches should be encouraged in the fields of fisheries and aquaculture by supporting the development of genomic resources, such as BAC libraries, fine scale linkage maps, EST databases and expression profiling.
  - International networks and large collaborative initiatives are essential so that projects such as full genome sequencing can be implemented and be exploited in various fields of fisheries and aquaculture.
  - Open access web-based resources, joining available genomic data (ESTs, mapping data, BAC fingerprinting and annotation...) should be developed in order to favour integrated collaborations (see also topic 4).
  - Studies of local adaptations in the wild and hatchery populations should incorporate genomic approaches to further understand the footprints of selection at a genome wide level.
  - Potentials of molecular marker assisted selection and domestication process in aquaculture species should be further explored, benefiting from the development of new genomic resources and computational and analytical tools.

- 4) Populations, and for gaining insight into the geographic and ecological factors controlling the development of population boundaries.
  - Before starting a sampling programme for a particular species we recommend that all available information on biological and physical parameters, including geographical features, hydrographical data and geological information, be taken into consideration. In terms of biological parameters we need information such as: migration pattern, spawning areas, extent of philopatry, spawning time, feeding grounds, growth rate, natural and fishing mortality.
  - In order to compare genetic and geographic information it is necessary to identify stage in the life cycle where populations are most discrete. This will generally be the spawning stage. We recommend that an optimal sampling strategy be devised, depending on the species
  - We recommend using the most appropriate molecular methods in a comprehensive spatial survey, incorporating as far as possible a temporal component.
  - It is recommended that genetic and geographic information be combined using the most appropriate landscape genetics approaches, e.g. currently BARRIER and AIS.
  - We recommend attempting to explain results from landscape genetics software in terms of available physical and biological information in order to improve predictive capacity and make best use of the results of analysis.
  - To delineate the spatial extent of each population using survey, we recommend using both physical and genetic data.
  - Having defined populations that at other stages of the life cycle where population mixing may occur we recommend that approaches based on MSA/IA be used to estimate proportions in the mixture and population identity of individual animals.
  - As an overarching recommendation, given that methods are now available for many species of identifying structuring into breeding populations, it is recommended to fisheries managers that these methods be used in conjunction with geographical information systems to define the spatial and temporal 'footprint' of these breeding populations in order to allow population focused management.
  - We recommend that future work involve further investigations of the relationship between geographical information and population genetics, so that maximal use can be made of the synergy between these two fast developing fields.
- 5) Current and future prospects of QTL-based studies in fisheries and aquaculture.
  - QTL studies should be supported in both in wild and farmed aquatic species as they are one of the most direct ways to understand the genetic basis of phenotypic variation, linking classic quantitative genetic and genomic studies.
  - QTL studies should not be restricted to MAS. The development of QTL studies should be supported as they can also contribute to a better understanding of the genetic architecture of adaptive traits of interest to fisheries and their management.

- To aid identification of QTL in a wider variety of aquatic species, the current development of genomic resources - notably linkage and physical maps, EST and BAC libraries and whole genome sequences - should be encouraged.
  - The development of statistical methods and software adapted to aquatic species should be supported to facilitate the development of linkage maps and to identify QTLs.
  - The development and maintenance of divergent lines, segregating progenies, or other biological material of interest for QTL mapping should be encouraged.
- 6) Update and insights from the EU project SALSEA-Merge on establishment of a large-scale genetic database for assigning individual to population of origin.
- Support and promote extension of the SALSEA-merge database for European Atlantic salmon stocks to encompass stocks in the Western Atlantic.
  - Support endeavours to extend work on the use of genetic markers to advance understanding of the marine ecology of Atlantic salmon beyond the life of the existing EU SALSEA-Merge project.
  - Review the potential of use molecular genetic markers in other marine species under ICES remit for monitoring spatial and temporal movements of individuals, populations and stocks to advance understanding of their marine ecology
- 7) Pursuing the establishment of a meta-database cataloguing molecular data in the field of fish and shellfish population genetics.
- A working demonstration meta-database of molecular population genetic information be developed for the Atlantic salmon, building on the EU SALSEA Merge project, to assess the benefits, feasibility and practical operational issues of developing a full, multispecies meta-database.
- 8) Interaction of marine escaped farmed finfish on wild fish populations at a local and regional scale, and specific aspects for reducing uncertainty in risk assessment.
- the collection of basic biology knowledge of new candidate and establish species in aquaculture; behaviour and reproduction;
  - that research be supported to provide information related to risk assessment to the following production technologies; sterile fish, local brood-stock, cage technology;
  - that a review on “lessons learned” from other more established farmed species (agriculture and aquaculture) is carried out;
  - that a genetic inventory of wild populations of target species is undertaken.
- 9) Potential for using parasites, microbes and viruses as “magnifying glass” for fish stock characterization.
- It is recommended, given that parasite population genetics can be a proxy for identifying host fish populations (including farmed and native groups), make good use of it, when appropriate to the research question addressed. This requires promoting interdisciplinary interaction between fish biologists, fisheries scientist, ecologists, evolutionary biologists, parasitologists,

bacteriologists and virologists in order to enhance parasite supported stock.

- 10 ) Use of adaptive SNPs and other adaptive markers for genetic identification of populations (breeding stocks).
  - That genetic markers under directional selection continue to be identified and employed in genetic stock identification analysis as such markers have been shown to yield informative insights on both the scale and dynamics of populations and in identifying potential underlying drivers.

### 1.5.2 References

- ICES. 2006. Report of the Working Group on the Application of Genetics in Fisheries and Mariculture (WGAGFM), 24–27 March 2006, Newport, Ireland. ICES CM 2006/MCC:04. 59 pp.
- ICES. 2007. Report of the Working Group on the Application of Genetics in Fisheries and Mariculture (WGAGFM), 19–23 March 2007, Ispra, Italy. ICES CM 2007/MCC:03. 70 pp.
- ICES. 2008. Report of the Working Group on the Application of Genetics in Fisheries and Mariculture (WGAGFM), 1–4 April 2008, Pitlochry, Scotland, UK. ICES CM 2008/MCC:04. 77 pp.
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- ICES. 2012. Report of the Working Group on the Application of Genetics in Fisheries and Mariculture (WGAGFM), 4–6 May 2011, Bangor, UK. ICES CM 2011/SSGHIE:13. 82pp.
- ICES. 2012. Report of the Working Group on the Application of Genetics in Fisheries and Mariculture (WGAGFM), 2–4 May 2012, Derio, Spain. ICES CM 2012/SSGHIE:12. 61 pp.

## 1.6 ICES Working Group on Environmental Interactions of Mariculture (WGEIM)

Table 1.6. Aquaculture related topics from the Working Group on Environmental Interactions of Mariculture (WGEIM).

Topic	2002	2003	2004	2005	2006
1	Issues of environmental impact, sustainability and technological change				
2	Diversify production through new species				
3	Offshore farming				
4	Alternate protein and lipid use				Fish feed

5	Assess the relationships between WFD targets and aquaculture requirements.
6	Potential impact of escaped non-salmonid aquaculture candidates on local stocks
7	Sea lice Treatment
8	Evaluate examples of sustainability indices proposed for mariculture operations and provide specific recommendations on utility of proposed
9	The current state of development of integrated culture systems (IMTA) with a view to assessing the potential of polyculture to mitigate the environmental effects of mariculture

**Table 1.7. Aquaculture related topics from the Working Group on Environmental Interactions of Mariculture (WGEIM; continued).**

Topic	2007	2008	2009	2010	2011	2012
4		Feed use				
7						Treatment of sea lice – well boats
8		Evaluate examples of sustainability indices proposed for mariculture operations and provide specific recommendations on utility of proposed				
9		The current state of development of integrated culture systems (IMTA) with a view to assessing the potential of polyculture to mitigate the environmental effects of mariculture				
10		Climate change and Aquaculture				
11		Fouling hazards				
12				Effects of mariculture on wild fish (OSPAR request)		

### 1.6.1 Summary of WGEIM publications on aquaculture topics

- Black E. A. and I.M. Davies, 2008. Introduction. In: IMO/FAO/UNESCO-IOC/WMO/IAEA/UN/UNEP/UNIDO Joint Group of Experts on Scientific Aspects of Marine Environmental Protection (GESAMP) 2007. Assessment and communication of environmental risks in coastal aquaculture. Rome, FAO. GESAMP Reports and Studies (76): 200p.
- Davies I.M. and E.A. Black, 2008. Environmental effects, risks and uncertainties associated with coastal aquaculture. In: IMO/FAO/UNESCO-IOC/WMO/IAEA/UN/UNEP/UNIDO Joint Group of Experts on Scientific Aspects of Marine Environmental Protection (GESAMP) 2007. Assessment and communication of environmental risks in coastal aquaculture. Rome, FAO. GESAMP Reports and Studies (76): 200p.
- Black E.A. and I. M. Davies, 2008. Risk analysis. In: IMO/FAO/UNESCO-IOC/WMO/IAEA/UN/UNEP/UNIDO Joint Group of Experts on Scientific Aspects of Marine Environmental Protection (GESAMP) 2007. Assessment and communication of environmental risks in coastal aquaculture. Rome, FAO. GESAMP Reports and Studies (76): 200p.
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- McKindsey CW, Thetmeyer H, Landry T, Silvert W (2006) Review of recent carrying capacity models for bivalve culture and recommendations for research and management. Aquaculture 261:451-462
- McKindsey CW, Landry T, O'Beirn FX, Davies IM (2007) Bivalve aquaculture and exotic species: a review of ecological considerations and management issues. Journal of Shellfish Research 26: 281-294.
- O'Beirn FX, McKindsey CW, Landry T, Costa-Pierce B (2012) Methods for sustainable shellfish culture. In: Meyers RA (ed) Encyclopedia of Sustainability Science and Technology. Reference Editorial Office, Springer, p 9174-9196

### 1.6.2 Summary of WG advice/recommendations on aquaculture topics by topic:

- 1) Review issues of environmental impact, sustainability and technological change in mariculture
  - a) In order to foster a sustainable development of coastal and marine aquaculture, there is a need to diversify production and to cultivate new species. A proactive approach is required to avoid mistakes made previously when salmonid farming was developing. Mitigation strategies based on sound scientific criteria in relation to the species under consideration need to be prepared at an early stage of development. Studies would have to consider the status of the natural stocks in the area, the potential genetic, trophic and behavioural interactions, and, foremost and specifically, the development of methods for recovery of escaped fish in the event of large-scale escapements. This subject seems to be of particular importance for non-migratory fish stocks with small localized populations (e.g. sea bass and sea bream), or migratory species with different migratory patterns than salmonids (e.g. cod, halibut, turbot, and wolffish and other species).
  - b) MARAQUA project, recommended that in some instances environmental studies of a more limited nature could be carried out and the results provided to the regulatory authorities in the form of an "Environmental Report" when making an application for a shellfish-farming permit. The WGEIM noted that the preparation of such reports should ideally be done on a case-by-case basis and the information should be relevant to the specific site and local conditions.
  - c) WGEIM considered that the cumulative impacts of many small operations could be significant and that appropriate management and regulatory strategies need to be developed to minimize these impacts. Such strategies will require the development of carrying capacity models, and the setting of Environmental Quality Objectives (EQO) and Environmental Quality Standards (EQS), which ideally should be part of a science-based Integrated Coastal Zone Management system.
  - d) A number of technologies and support systems are currently under development, some of which have been outlined in the WGEIM 2002 Report. These should be evaluated and compared, with the aim to prepare a review publication on the requirements for a DSS system tailored to the needs of mariculture that builds on the state-of-the-art and/or links to existing systems.
- 2) Assess the relationships between the Water Frame Directive (WFD) targets and the requirements of aquaculture.
  - a) As the targets for improvements in water quality will be defined within the WFD system, it is important to assess the relationships between the WFD targets and the requirements of aquaculture.
  - b) WGEIM recommends the potential impacts of new EU legislation on Mariculture activities should continue to be monitored by the group. In addition, the EU marine strategy will extend beyond the limits of the WFD. Aquaculture expansion into more open waters



may be impacted by this initiative. It is important that the group (and ICES) be aware of the developments in relation to this legislation

### 3) Offshore farming

- a) Member Countries support research on the performance of new offshore farming systems and on the operational risks and environmental interactions associated with such new farming systems. The Mariculture Committee should through its national members foster the collection of information on national activities in this area to be considered by the working group during the next meeting.
- b) Although offshore farming systems are currently under development and several are already being used on a trial basis, there is a long learning process ahead in the needs of the infrastructure for operating such systems. Although being mainly distant from the coast, there is a need for a land base and for support systems that may require specific developments and control measures to prevent unforeseen hazards. Are the automated monitoring tools currently available adequate to safeguard offshore systems? What control measures and rescue strategies and options exist in extreme situations? Besides these technical aspects, there are a number of biological factors that may be operating at different levels than in inshore farms (e.g. behavioural aspects, biotechnology of sorting, application of counting and measuring techniques, monitoring for mortalities and their recovery, etc.
- c) A number of technologies and support systems are currently under development, some of which have been outlined in the WGEIM 2002 Report. These should be evaluated and compared, with the aim to prepare a review publication on the requirements for a DSS system tailored to the needs of mariculture that builds on the state-of-the-art and/or links to existing systems

### 4) Alternate use of protein and oil/ Fish feed/ Feed use

- a) The high prices and the lack of opportunities to expand the capture fishery make it imperative that alternate protein and lipid sources be developed for use in aquafeeds.
- b) The main recommendation is that during the intersession (from 2006), WGEIM lead a review and evaluation of recent advances on alternative sources of lipid and protein to fishoil and fishmeal in aquafeed. It is proposed that a WGEIM review a draft manuscript at the 2007 meeting that is to be submitted for publication in a peer reviewed scientific journal.
- c) WGEIM to provide an update on finfish feed usage and constituents from member countries to include in the meeting report in 2009.

### 5) Potential impact of escaped non-salmonid aquaculture candidates on local stocks.

- a) Monitoring for sexual maturity and spawning activities should be carried out on farms that rear cod beyond the normal age of sexual maturity (two years) and be available in aggregate for the in-

dustry. Such monitoring might assist in addressing the question of whether photoperiod manipulation is effective in delaying sexual maturation and identify where the potential risk of egg releases could occur. The potential to recapture escaped cod has not been analysed; but is an important area for Research.

- b) Studies to determine the survival of escapees, their migration patterns in relation to their location (e.g. inshore or offshore) and the season they are released. The impact of releases in summer may be different from winter, when sea bass are not feeding intensively but are reproducing.
  - (i) Development of tools to distinguish wild fish from escapees.
  - (ii) Better information on the structure and habitat use of wild populations.
  - (iii) Development of offshore systems to reduce interactions with inshore wild populations.
  - (iv) Monitoring the behaviour of adults and juveniles released in offshore locations. It would be especially helpful to invest in this type of research now, before the
  - (v) cultured stock used by industry has had time to further genetically differentiate from local stocks.
  - (vi) The efficacy of photoperiod control on maturation.
  - (vii) Another possible approach, not specific to sea bass, could be to produce fish that genetically do not synthesize some essential dietary component which they can only find in artificial feed. This would make the fish unable to survive in the wild. However this solution is highly hypothetical and needs substantial theoretical development (animal welfare, technical feasibility) but could also be applied to GMO fish if they are adopted by the industry.
  - (viii) One way to decrease the impact of releases in a given environment would be to maximize the wild stocks in areas where farming activities are based, particularly where wild stocks are scarce. This would require tools to be available to evaluate these wild stocks.
  - (ix) Tools to permit the recognition of wild fish from escapees are not readily available, and new developments are necessary to implement their monitoring.
- 6) Evaluate examples of sustainability indices proposed for mariculture operations and provide specific recommendations on utility of proposed.
  - a) Management of aquaculture activities in marine systems is dependent upon a number of broad principles.

- (i) All activities carried out in the marine environment will impact on the system in some fashion
  - (ii) These impacts can be measured at some scale be it global, regional and local;
  - (iii) The determination of ecological thresholds relating to impact can be informed by scientific investigation; and
  - (iv) Ultimately the level of impact permitted is a policy decision made by managers and informed by societal values.
- b) The establishment of thresholds relating to specific indicators is an important consideration when determining the ecological tolerance of the system to perturbations. Impact indicators have some capacity to measure habitat resilience and recoverability. Coupled with scenario building, ecosystem modelling provides a mechanism to explore resilience and tipping points in habitats and ecosystems.
- c) The level of environmental/ecological change deemed acceptable in a system as a consequence of a specific (or combination) of activities is governed primarily by social and/or economic views.
- d) Ideally, a sustainability indicator applicable to aquaculture should be able to incorporate all information in a system, identify what the goals (global vision) for the system are, and evaluate both positive and negative aspects of any proposed development. It is apparent that in order for managers to apply a system-wide view of sustainability, they would have to take into account a broad range of pressures and would define clearly what might be permissible and acceptable (i.e. social carrying capacity guided by legislative or policy drivers).

#### 7) Treatment of sea lice

- a) A risk management approach should be used to determine treatment strategies.
- b) The ecological risk of the sea lice therapeutants were assessed by reviewing information on their distribution and persistence in the marine environment, their biological effects observed on marine organisms in laboratory and field studies, and the likelihood that these biological effects would occur during the use of these chemicals to treat sea lice infestations of cultured salmon.
- c) Although near- and far-field effects may be anticipated, there is great variation among species and chemical compounds and a paucity of data to predict how effects may be manifest.
- d) Site-specific factors (hydrological and biological) are likely of great importance.
- e) (2012) Guidance on assessment of the risks associated with discharges from mobile well-boats and cost-effective solutions to reduce the discharged quantities of lice or treatments to the marine environment would be of great benefit to regulators and industry alike and may result in a significant increase in effectiveness of sea lice treatments in Scotland.

- 8 ) Evaluate examples of sustainability indices (that take social values into consideration (2012)) proposed for mariculture operations and provide specific recommendations on utility of proposed.
  - a ) Appropriate decision support systems (DSS) should consider the spatio-temporal requirements of mariculture together with the requirements of other activities.
  - b ) The issues of sustainability of mariculture and sustainability indices have been addressed by the WGEIM, WGMASC, and other EGs and groups for a number of years. Reviews mostly focus on “impact indicators” whereas “sustainability indicators” also include social factors, including what is deemed to be “acceptable” by various stakeholders. These latter indices also include other activities within a given area within the context of ICZM.
  - c ) All activities should be considered when licensing activities in a system, i.e. both positive and negative aspects must be measured.
  - d ) (2012) Issues relating to the sustainability of aquaculture have a strong social component and are best considered within the context of an Integrated Coastal Zone Management (ICZM) framework and Socio- Economic Dimensions of Aquaculture (SGSA).
- 9 ) The state of development of integrated culture systems (IMTA) with a view to assessing the potential of polyculture to mitigate the environmental effects of mariculture
  - a ) Review of existing Integrated Multi-Trophic Aquaculture IMTA programs and specific projects continues as a Term of Reference for WGEIM 2009. In addition it is proposed to expand this ToR in order to address the issue of energy and nutrient cycling associated with IMTA systems and report in 2009.
  - b ) (2012) Issues relating to multi-trophic aquaculture remain an active EG theme to address issues raised in the current document. This includes (but is not limited to) issues relating to ocean ranching of echinoderms.
- 10 ) Climate change and Aquaculture
  - a ) Assessing the potential impact of climate change on aquaculture activities is a useful scenario setting exercise that might be conducted in all member states involved in marine aquaculture.
- 11 ) Fouling hazards
  - a ) Continue to investigate fouling hazards associated with the physical structures used in mariculture with a view to developing integrated pest management strategy using case studies from Canada and Spain and report in 2009.
  - b ) To define the types of information that is needed to develop an integrated pest management strategy.
  - c ) Overview of the types of information needed to establish an integrated pest management strategy for tunicates in bivalve aquaculture. A comparison of the situation in Spain (Galicia) and eastern Canada (Prince Edward Island) is given to contrast two situations with different levels of infestation (PEI > Galicia, using *Ciona* in-

testinalis as a target species) to suggest insights into potential explanations for the observed differences in tunicate loads.

- d) Fouling hazards and integrated pest management strategies should be developed in more detail with respect to i) therapeutant release, ii) waste management, and iii) propagule pressure within the context of a risk assessment framework.

#### 12) Effects of mariculture on wild fish (OSPAR request 2010/3)

- a) The risk assessment is visualized in table 4.4.1 of the report ICES CM 2010/SSGHIE:08. Use of fish for feed is the only component analysed that has a high risk of impacting wild stocks in this analysis.

### 1.6.3 References

- ICES. 2002. Report of the Working Group on Environmental Interactions of Mariculture (WGEIM), 8–12 April 2002, ICES Headquarters, Denmark. ICES CM 2002/F:04 101 pp.
- ICES. 2003. Report of the Working Group on Environmental Interactions of Mariculture (WGEIM), 31 March–4 April 2003, Vigo, Spain. ICES CM 2003/F:04 114 pp.
- ICES. 2004. Report of the Working Group on Environmental Interactions of Mariculture (WGEIM), 8–12 April 2004, Galway, Ireland. ICES CM 2004/F:02 100 pp.
- ICES. 2005. Report of the Working Group on Environmental Interactions of Mariculture (WGEIM), 11–15 April 2005, Ottawa, Canada. ICES CM 2005/F:04 116 pp.
- ICES. 2006. Report of the Working Group on Environmental Interactions of Mariculture (WGEIM), 24–28 April 2006, Narragansett, Rhode Island, USA. ICES CM 2006/MCC:03 201 pp.
- ICES. 2007. Report of the Working Group on Environmental Interactions of Mariculture (WGEIM), 16–20 April 2007, Kiel, Germany. ICES CM 2007/MCC:02 64 pp.
- ICES. 2008. Report of the Working Group on Environmental Interactions of Mariculture (WGEIM), 14–18 April 2008, Victoria, B.C. Canada. ICES CM 2008/MCC:03 61 pp.
- ICES. 2010. Report of the Working Group on Environmental Interactions of Mariculture (WGEIM), 29 March–2 April 2010, Galway, Ireland. ICES CM 2010/SSGHIE:08 68 pp.
- ICES. 2012. Report of the Working Group on Environmental Interactions of Mariculture (WGEIM), 20–23 March 2012, Sopot, Poland. ICES CM 2012/SSGHIEF:16 59 pp.

## 1.7 ICES Working Group on Pathology and Diseases of Marine Organisms

Table 1.8. Aquaculture related topics from the Working Group on Pathology and Diseases of Marine Organisms (WGPDMO)

Topic	2005	2008	2009	2010	2011	2012
1	National reports on disease and new disease trends (for Mariculture for instance HSMI, VHS, ISA, francicella and sea lice)					
2	Fish disease index (FDI)					
3	Sea lice interaction between farmed and wild fish					
4	Disease in bivalves					
5	International collaboration and networks					
6	Disease modelling wild and farmed fish					

### 1.7.1 Summary of WGPDMO publications on aquaculture topics

Murray, A. G. 2008. Existing and potential use of models in the control and prevention of disease emergencies affecting aquatic animals. Rev. sci. tech. Off. int. Epiz., 27(1): 211–228.

### 1.7.2 Summary of WGPDMO outputs on aquaculture topics

2005:

- A number of new disease trends in wild and farmed fish and shellfish were reported by Member Countries for 2004.
  - Heart and skeletal muscle inflammation (HSMI) is a major and increasing disease problem for Norwegian Atlantic salmon aquaculture.
  - According to a review on the role of plankton in gill-related mortality in farmed fish in contact with planktonic organisms (e.g. jellyfish) may result in mass mortality in farmed Atlantic salmon (*Salmo salar*).
- Due to multiple factors influencing wild fish populations, no firm conclusions can yet be drawn regarding the extent of sea lice interactions between farmed and wild fish and the effect on wild salmon.

2008:

- Heart and Skeletal Muscle Inflammation and Pancreas Disease continue to show an increasing trend in Norway. HSMI was seen for the first time in freshwater fish. PD remains endemic in Irish salmon farms.
- A swarm of the jellyfish, *Pelagia noctiluca*, caused for the first time 100% mortality at an Atlantic salmon farm in Northern Ireland.
- Review the information on *Francisella* sp. and visceral granulomatosis in farmed cod and the potential for disease interaction between wild and farmed cod.

- Review the evidence of increased tolerance by *Lepeophtheirus salmonis* to chemotherapeutants: 1 ) Treatment of sea lice can be effective but this is costly and access to efficacious medicines and pesticides is limited to a small number of available compounds and by regional or national regulatory processes. 2 ) The limited available information provides evidence of increased parasite tolerance to four classes of compounds: organophosphates, pyrethroids, hydrogen peroxide and avermectins.
- WGPDMO noted that there is an increasing number of international collaborative actions involving fish and shellfish disease and pathology, reflecting the importance of disease issues in relation to environmental monitoring and assessment as well as to mariculture.

2009:

- Overview of diagnosed viral cases in Norwegian salmonid farms of viral haemorrhagic septicaemia (VHS), infectious salmon anaemia (ISA), infectious pancreatic necrosis (IPN), salmonid alphavirus (SAV), heart and skeletal muscle inflammation (HSMI) for the period 1999–2008.
- The first outbreak of IHN in The Netherlands occurred in a rainbow trout farm.
- Salmonid alphavirus infection is a cause of significant losses in farmed Atlantic salmon in Ireland, Norway and Scotland.
- Repeated treatment failures have led to the suspicion of multi-resistance in a salmon louse population against several compounds used for oral and bath treatment in Norway.
- Francisellosis has continued to increase in Norway since it was first detected in 2004 and is considered the most significant disease on cod farms.
- Gill disorder remains a serious problem on Irish salmon farms. It is considered to be a multifactorial disorder and a research programme has been initiated to investigate the problem.

2010:

- National reports: Wild and Farmed fish and shellfish (molluscs and crustaceans) PD decreasing in Norway, IPN increasing in Norway; Francisella found in cod in Ireland; Sea lice numbers increasing in Norway and USA, evidence of resistance development.
- Summarize the current state of knowledge of parasite interactions from finfish mariculture on the condition of wild fish populations (both salmonid and non-salmonid) both at a local and regional scale.

2011:

- *L. Salmonis* (salmon lice) is considered the biggest threat to marine survival of salmonids

2012:

- Review of occurrence and mitigation of pathogen transfers from mariculture fish to wild populations.

### 1.7.3 Summary of WG advice/recommendations on aquaculture topics:

2005:

- Available new information on the causes and effects of heart and skeletal muscle inflammation (HSMI) affecting farmed Atlantic salmon (*Salmo salar*) in ICES Member Countries are reviewed by WGPDMO for the 2006 meeting.

2008:

- Fish disease monitoring data will be useful in evaluating the effects of climate change on fish health and provide better understanding of pathogen interactions between wild and farmed fish.
- ICES Member Countries conduct further research to refine diagnostic tools and to develop treatments or vaccines for francisellosis in farmed cod.
- ICES Member Countries i) encourage research to identify and license new classes of sea lice medications; ii) encourage salmon aquaculture companies to practise integrated pest management, including synchronized treatments within management areas, use of alternating classes of sea lice medication, and routine sea lice monitoring; iii) encourage coordinated use of bioassay techniques to screen for tolerance to medicines and pesticides;
- Communication networks of diagnostic practitioners and internationally recognized experts in aquatic animal health in ICES Member countries be established and maintained.

2009:

- WGPDMO Members are encouraged to provide information on diseases in farmed fish using the new standards and guidelines.
- Francisellosis should be followed and new information about outbreaks, diagnostic improvements, host susceptibility and further developments in vaccine production should be included in the national reports.

2010:

- In order to reduce the risk of sea lice interactions between farmed and wild fish, ICES Member Countries:
  - Recommend to establish salmon mariculture production thresholds, based on capacity to produce salmon louse larvae, in coastal ecosystems currently or potentially occupied by salmon mariculture.
  - Encourage and support the development of hydrodynamic and particle tracking modelling studies of coastal ecosystems currently or potentially occupied by salmon mariculture and other types of mariculture.
  - Support the development of measures to reduce the risk associated with salmon lice interaction between farmed and wild fish by developing novel efficient and environmentally safe therapeutics, vaccines and technical measures such as barriers between farms and the environment.
  - Should establish and maintain systematic monitoring programmes of salmon lice on salmonids in coastal areas with, or likely to have, salmon mariculture.



- In light of the expanding mariculture industry, ICES Member Countries should enhance research and monitoring activities addressing interactions between other fish and shellfish species and other diseases and parasites, including potential population effects.

2011:

- It is important to use disease monitoring data in wild populations to provide baseline data prior to cultivation/ mariculture activities.

2012:

- WGPDMO recommend renewed contact with WGEIM (now WGAQUA)

#### **1.7.4 References**

- ICES. 2005. Report of the Working Group on Pathology and Diseases of Marine Organisms (WGPDMO), 8–12 March 2005, La Tremblade, France. ICES CM 2002/F:02 112 pp.
- ICES. 2008. Report of the Working Group on Pathology and Diseases of Marine Organisms (WGPDMO), 4–8 March 2008, Galway, Ireland. ICES CM 2008/MCC:01 128 pp.
- ICES. 2009. Report of the Working Group on Pathology and Diseases of Marine Organisms (WGPDMO), 24–28 February 2009, Riga, Latvia. ICES CM 2009/MCC:01 119 pp.
- ICES. 2010. Report of the Working Group on Pathology and Diseases of Marine Organisms (WGPDMO), 23–27 February 2010. Uppsala, Sweden. ICES CM 2010/SSGHIE:02 66 pp.
- ICES. 2011. Report of the Working Group on Pathology and Diseases of Marine Organisms (WGPDMO), 1–5 March 2011, Aberdeen, UK. ICES CM 2011/SSGHIE:04 58 pp.
- ICES. 2012. Report of the Working Group on Pathology and Diseases of Marine Organisms (WGPDMO), 31 January–04 February 2012. Lisbon. Portugal. ICES CM 2012/SSGHIE:03 74 pp.

## Annex 4: Emerging issues

Table I Emerging and relevant issues sorted by thematic group as defined by EATiP and topics addressed in the WGAQUA group discussion

Thematic groups suggested by EATiP	Central topics defined by WGAQUA
Integration with the Environment	Benthic impacts Introduction of new species and transfer of species between countries Interaction of escapees with natural environment (genetic, ecological) Ecological carrying capacity Introduction of hard substratum/ structures Capture based aquaculture Interaction with wild populations/species
Technology and Systems	Off shore (exposed) Land-based, RAS Prevent escapees Enclosed systems (e.g. sea cages) IMTA, nutrient trading, upwelling Juvenile supply Production practice Macroalgae production Pest management (biofouling and predator control)
Product quality, Consumer Safety and Health	Traceability (genetic, farm to fork and fork to farm) Different feed (organoleptic, fish quality/taste, health value, fish health) Functional food (omega 3)
Managing the Biological Life cycle	Domestication Improving yield of hatcheries Juvenile quality Optimizing production cycle
Sustainable Feed Production	Feed sources (how to use available sources or produce feed for fish – mussels/macroalgae/single cell proteins/invasive species/plant production) GMO (soymeal supply) Phytoplankton production (feed, biofuel?)
Knowledge Management	Tools to make scientific and technological knowledge available to managers and industry
Aquatic Animal Health and Welfare	Pest management (sea lice) Fish welfare

Table II Emerging and relevant issues suited to be addressed by other groups within ICES

Topic	ICES group suggested to take on this topic
Socio-economics (externalities, viability, coastal communities, food security)	SGSA
Microplastics	Mar Chem
Climate change	Several groups
Disease, probiotics, vaccine development, medicines	WGPDMO
Marine spatial planning (combinations?, zonation ICZM, spatial scale)	WGMPCZM
Hydrodynamic modelling (currents, waves) oceanographic EG, tidal energy group	ecosystem groups
Natural dynamic condition (time-scale)	
Harmful algal blooms	WGHABD
Transport (well boat, pest management)	WGITMO WG Ballast water
Statistical and analytical methods for quantifying genetic introgression of farmed escaped salmon in native populations	WGAGFM

### Socio-economics, Management and Governance

- Market (development, segmentation, differentiation, branding)
- Educated consumer
- Training aquaculture people
- Monitoring program (indicators and thresholds)
- Risk assessment
- Need for regulations, EU directives, licencing (space, time, environment) EATiP
- Standards
- Carrying capacity
- Marine spatial planning of aquaculture (combinations?, zonation ICZM, spatial scale) joint meeting with WGMPCZM