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14-18 APRIL 2008

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Executive summary

WGEIM met in Victoria, British Columbia, Canada from 14–19 April, 2008. The meeting was attended by 18 scientists representing 7 countries. The location facilitated a joint-meeting between ICES WGEIM and PICES (North Pacific Marine Science Organisation). Issues of common interest were discussed in the course of the meeting and broadly reflected the past and current Terms of Reference of WGEIM. The meeting highlighted that the issue of sustainability and the measurement of such is uppermost in most jurisdictions but that the levels (thresholds) assigned to acceptability of environmental impact vary considerably between Europe/North America and Asia. The PICES group considered the feasibility of establishing a group similar to WGEIM and prepared a justification brief for the PICES secretariat. WGEIM reviewed the draft ICES Science Plan and strongly recommended that given the global importance of mariculture, it is important that ICES continue to include mariculture as a primary focus in Action and Science plans. In addition, four existing terms of reference were addressed by the group and are summarised below.

ToR a): Sustainability indicators are different from “impact” indicators in that they are more comprehensive and include considerations of not only environmental but also social and economic sustainability. WGEIM believe it is the proper role of the group to better define environmental indices that represent discernible environmental changes as a result of mariculture rather than involve itself in discussions of economic and social indicators where it has no expertise. Upon reviewing previous ICES WGEIM reports, WGEIM have decided to remove the traffic light concept and develop an alternative, more industry relevant system. The primary forms of environmental interaction of marine fish cultivation are linked with an expression of acceptable effects on the marine environment, indicating the desirable direction of change leading to progressively improving levels of sustainability. WGEIM addressed this from national or regional scales rather than local (e.g. individual farm site) when proposing the range of indicators, although certain indicators may be transferable to smaller scale assessments. WGEIM members will work during the intersession to apply the chosen environmental indices to mariculture industries in selected ICES countries.

ToR b): The group further investigated the topic of fouling associated with the physical structures used in mariculture with a view to developing integrated pest management strategies. As opposed to discussing specific mitigation strategies, the group concentrated on the information (biological and/or physical) required to inform the development of management strategies. To illustrate, a proposed joint Canada-Spain cooperative research programme to evaluate mechanisms that lead to the establishment and perpetuation of pest tunicate species was discussed. The project highlights the similarities and difference observed between the systems, the cultured species and the pest species (i.e. ascidians). It is proposed that there are a number of factors that may be responsible for the contrasting levels of infestation between eastern Canada and Spain. Among many, there is the possibility that hydrodynamic conditions alone or in concert with hydrodynamic-biological interactions create such differences. There is also the possibility that there is something intrinsically different with respect to the mussel lines themselves. Either differences in the mussels themselves and/or the communities associated with the mussels (in terms of diversity, trophic structure, etc.) may account for differences in pest loads. Alternatively, differences with respect to the tunicates themselves may account for differences in pest loads. A series of studies that are proposed to better understand the potential importance of the vari-

ous factors outlined above to the establishment and perpetuation of *C. intestinalis* populations in mussel aquaculture in order to implement a logical integrated pest management strategy to control the abundance of the species.

ToR c): ICES-WGEIM has documented previously that IMTA is being pursued, as pilot-scale research projects, in a number of locations among its member countries. Canada, in particular, is progressing rapidly with the commercialization of IMTA with projects (linked with business development) occurring on both the Atlantic and the Pacific coasts. These initiatives are concurrently addressing system engineering, ecological balance, materials/energy flow, governance, as well as socio-economic aspects of this approach to multi-species aquaculture production. In summary, encouraging results in terms of growth and performance for all components have been highlighted. Regulatory constraints (i.e. single species per site) still need to be resolved.

ToR d): An outline was generated relating to the ToR on seed quality. The aim of this paper (to be presented in 2009) will be to investigate the balance of risk and benefits of the environment performance (footprint) with economic performance (profitability) as a consequence of the improvement of seed quality in aquaculture systems. Environmental performance will be divided in two categories i) intake (i.e. increasing conversion efficiency) and ii) output. (i.e. reducing output/waste while maintaining production).

The next meeting was arranged for April 20-24 at the Marine Institute, Galway, Ireland.

1 Opening of the meeting

Dr. Francis O'Beirn (Chair) opened the 2008 meeting of the Working Group on the Environmental Interactions of Mariculture (WGEIM) hosted by Dr. Stephen Cross at the University of Victoria, Victoria, British Columbia, Canada 14–18 April. This year's meeting was attended by 18 scientists from seven countries (Annex 1).

The meeting was co-sponsored by the University of Victoria and the North Pacific Marine Science Organisation (PICES). A goal of the meeting was discuss issues of common interest and foster formal links between ICES and PICES. The group was welcomed to Victoria by Dr. Stephen Cross who outlined some of the proposed events for the week. The Chair, on behalf of the group, expressed considerable gratitude to Drs. Cross and Alex Bychov of PICES for their considerable coordination efforts and providing facilities for the meeting and organising activities for the week. A brief introduction of both ICES and PICES was provided by the Chair of WGEIM and Dr. Stewart (Skip) McKinnell (Deputy Executive Secretary) of PICES.

2 Adoption of the agenda

The Chair continued the meeting by giving an overview of the Agenda for the week (Annex 2), which was accepted by the group. A primary goal of the week was to conduct a joint meeting between ICES WGEIM and a group of scientists with interest in mariculture representing the North Pacific Marine Science Organisation (PICES) wherein topics of mutual interest were discussed. In the joint meeting, mariculture-related topics were discussed in plenary, which took the form of presentations followed by general discussion (ToR e).

In addition, the goal was to continue to work on a number of a number of recurring terms of reference, respond to the call for comments on the Draft ICES Science Plan for which comments were solicited and as a consequence identify a clear strategy with regard to existing terms of reference and identify new terms of reference consistent with the ICES Strategic Plan. Ultimately it was agreed that the group would endeavour to reinforce within ICES the importance of mariculture to World and North Atlantic food production.

While the first two days of the meeting were centred around a series of presentations and discussions on active and completed topics considered by WGEIM, the last two days dealt with completing or developing existing terms of reference (Annex 3), Consistent with other meetings of the group the working arrangements were described, whereby a series of sub-groups were formed each to address a specific term of reference (Annex 3). A sub-group leader was assigned based upon previous involvement who was responsible for compiling the contributions of the others within the group and reporting in plenary (Annex 3).

3 ToR a) – Indices for the environmental effects of mariculture (Leads: Ian M. Davies, Barry A. Costa-Pierce, Edward Black, Jon Chamberlain)

3.1 Background

Sustainability indicators are different from “impact” indicators in that they are more comprehensive, including considerations of not only environmental but also social and economic sustainability. Recognizing this, members of the WGEIM believe it is the proper role of the WGEIM is to better define environmental indices that represent discernible environmental changes as a result of mariculture rather than involve itself in discussions of economic and social indicators where it has no expertise. WGEIM highlighted this deficiency in 2007 and recommended to ICES and MCC that such expertise be solicited from member countries in order to contribute on this ToR. The status of this request at the time of the meeting is unknown.

Upon reviewing previous ICES WGEIM reports, WGEIM have decided to remove the traffic light concept and develop an alternative, more industry relevant system. WGEIM members will also work during the intersession to apply our chosen environmental indices to mariculture industries in selected ICES countries (see below).

3.2 Classifying Types of Indicators by Use

For science to supply advice on management of marine species and ecosystems scientists need to be aware of how indicators fit with the broader structure of management knowledge. A useful structure for looking at that broad knowledge base and its associated classes of indicators is the commonly used “Driver-Pressure-State-Impact-Response” structure. Classes of such indicators include:

- 1) **Diagnostic (compliance) indicators:** Are people/industries following the rules?
- 2) **Status and trend indicators:** What is the status and trend of the ecosystem and its component properties? This could include ecosystem function indicators: how well is ecosystem function X being served, for example, the amount of a habitat needed to support a particular number of fish, for habitats of different state or quality. This could be used in evaluating compensation as well as achievement of ecological objectives.

- 3) **Limit indicators:** Are the conservation objectives (limits) being respected for properties essential to ecosystem structure and function?
- 4) **Target indicators:** Are policy aspirations being met?

These classes of indicators are not necessarily independent of each other. They can be thought of as functions that indicators may serve, and many indicators can serve more than one function. For example for eutrophication issues, concentrations of nitrogen in coastal waters may be used both as a limit indicator and a status and trend indicator

Indicators useful for management should be sensitive to pressures on the system, but need not necessarily diagnose exactly the mechanisms of change. They are effective as long as they give reliable signals to science and management in order to start examining the situation in detail. For several functions, particularly limit and target indicators, there should be a link between indicators and programs within which management undertakes decision making.

3.3 Ecosystem Indicator Selection Criteria

Defining a single set of indicators to be used by all regions is not practical, nor desirable, considering their differences in characteristics and objectives. The alternative would be to agree upon a set of selection criteria and a process to evaluate potential indicators. Using such a standard would provide formal justification for why an indicator might be used in one region but rejected for use by another region.

A preliminary list of indicator selection criteria found in Rice and Rochet (2005) is a starting point for discussion:

- Interpretation (Concreteness, Public Awareness, Theoretical Basis)
- Implementation (Availability of Historic Data, Cost, Measurability)
- Application (Sensitivity, Specificity, Responsiveness)

The following eight step framework is used to help tailor selection of indicators to optimally meet the above criteria (Rice and Rochet, 2005):

- 1) Determine users, their needs & objectives
- 2) Move from Objectives to candidate Indicators
- 3) Weight the screening Criteria
- 4) Score Indicators on the Criteria
- 5) Summarise results of the Scoring
- 6) Decide how many Objectives are required
- 7) Select the suite of Indicators
- 8) Report on status using the Indicators

3.4 Development of Practical Indices Related to the Sustainability of Aquaculture

The 2006 report of WGEIM noted that the Integrated Coastal Area Management (ICAM) guidance of UNESCO (2003) defines an indicator as a “parameter or value, which provides succinct information about a phenomenon”. The ICAM guidance has three basic categories of indicators, one of which is “environmental” described as follows:

Environmental: reflect trends in the state of the environment; are descriptive in nature; and become performance indicators if they compare actual conditions to desired conditions expressed in terms of environmental targets.

The combination of descriptive indicators with some expression of desired conditions or desired direction of change can provide a point of comparison (or threshold) for indicators of performance. Pathway is commonly used as a framework of pathways of effects. The WGEIM believes that “zero effects” is an unattainable goal that has little place in a discussion of sustainable development as it is a wholly unrealistic goal.

It has been recognized in numerous publications that the primary forms of interaction of marine fish farming with the marine environment are the occupation of space, benthic enrichment, nutrient release, genetic interaction, sourcing of feed materials, disease interactions with wild stocks, and energy consumption. Most of these interactions have been discussed at previous meetings of WGEIM. Transfer of diseases from farmed to wild stocks is outside the remit of WGEIM, and energy consumption has not been considered explicitly (and it has implications beyond the marine environment).

WGEIM considered each of these broad categories of impact/interaction processes and derived an expression of the theoretical condition in which the process are likely to have acceptable consequences for the marine environment. This may be considered as a crude expression of the ultimate state of sustainability in which undertake the enterprise (produce fish) in salt water, but have minimal effect on the marine environment. In some cases, this was relatively straightforward; ideally, there would be no enrichment of the sea bed arising from an adjacent fish farm operation, and there would be no nutrients released to the surrounding water.

In other cases, the expression is less straightforward, for example occupation of space cannot be avoided (unless land based systems are adopted) and minimisation of the occupation of space may be a more appropriate expression to use, as it retains the concept of continuous improvement through continuous minimisation.

WGEIM in 2007 compiled Table 3.1, which has been further refined by WGEIM in this report, in which each of the primary forms of environmental interaction of marine fish cultivation are linked with an expression of acceptable effects on the marine environment, indicating the desirable direction of change leading to progressively improving levels of sustainability. WGEIM had national or regional scales rather than local (e.g. individual farm site) in mind when developing Table 3.1, although aspects of the table may be transferable to smaller scale assessments.

Suggestions are made in Table 3.1 as to the measurements that could be employed to provide data for assessment of the directions of change, and the possible sources of such data. The WGEIM suggested that some of the proposed indices could be tested using data and modeling available, or obtainable, now, in all or some relevant ICES countries. Other indices, such as the life cycle analyses to assess energy consumption could in theory be done now, but would require significant input from experts in this form of industrial analysis. The WGEIM made no suggestions regarding disease transfer from farmed to wild fish.

WGEIM 2008 also concluded that the proposals in Table 3.1 appeared to be a development of the theoretical considerations in the 2006 and 2007 reports into a series potentially practical assessment tools. It was noted that the indices applied a very

broad brush to industries which were operating in diverse environmental settings, and that such variance was not taken into account.

Table 3.1. Selected Environmental Indicators for Mariculture.

Properties	Types of environmental interactions	Targets	Current state of the science	Proposed Index	Data sources	Feasibility	Comments on progress in ICES nations
Benthic communities	Benthic enrichment	No irreversible impacts on benthic communities, both near and far-field Compliance with national benthic standards	Global consensus that a “disturbance halo” around fed cages is ~100-200 m in circumference; Disturbance is reversed by fallowing ; Some evidence of far-field effects	Area of hypoxic and anoxic benthos per tonne of production	Modelling of impacted areas by site Use of ITI, AMBI, or sulphide standards	Could be done now	Ireland - 100% compliance with benthic standards from 2003 to 2006 Canada – data in provinces Scotland – data not compiled Chile – data in companies, not summarized USA – data in states, not summarized
Pelagic ecosystems	Nutrient Release Toxics Releases	Nutrient releases to surrounding water cause no impacts Farms use no toxics	Most releases are inorganic N, P Use of antibiotics very low in all ICES nations Use of slice widespread	Mass of nutrient N/P released per tonne of production Mass of medicines per tonne of production	Mass balance calculations by site or by industry sector	Could be done now	Scotland – Nutrient release estimates available from modeling <ul style="list-style-type: none"> Medicines use recorded and collated by SEPA

Properties	Types of environmental interactions	Targets	Current state of the science	Proposed Index	Data sources	Feasibility	Comments on progress in ICES nations
Fisheries Ecosystems: Target Species	Genetic interactions	Interactions with wild conspecifics cause no negative impacts	Some evidence of genetic pollution from salmon farms; much evidence from hatcheries Thorstad <i>et al.</i> (2008) reports that ~one-third of the total world production of Atlantic salmon is in regions where the species is exotic, and that hybridization of farmed with wild salmon has the potential to genetically alter native populations, reduce local adaptation and negatively affect population viability and character.	Number of escapees per year Number of escapees per year per tonne production	Reporting of escapees to a regional or national data centre	Feasible now in some countries	Scotland – Recording system for escapees is in place
Fisheries Ecosystems: Forage Species	Feeds for carnivorous fish	No impact on marine resources from forage fish removal due to technological advances in feeds or use of alternative feeds		Mass of marine oil/protein used Proportion of marine oil/protein used in feed Mass of marine oil/protein used per tonne of production	Reporting on use of feed types, feed compositions, and feed utilisation	Could be done now	Scotland – Information held by feed manufacturers. Details may be commercially sensitive.

Properties	Types of environmental interactions	Targets	Current state of the science	Proposed Index	Data sources	Feasibility	Comments on progress in ICES nations
Energy	Intensive high use	Minimised energy consumption in cradle-to-grave analysis of production		Energy consumption per tonne of production	Life cycle analysis in collaboration with growers and supply companies	Could be done now	Scotland – Theoretically possible to do the calculations, but not currently available.
Disease control	Use for prophylaxis	No use of medicines/pesticides		Amount (mass, number of doses) of medicines/pesticides used per tonne of production	National data centre, if available (e.g. Norway) Pharmaceutical companies Sampling of industry practice and experience Returns to EPAs	Probably only feasible now in some countries	Scotland – Medicines use recorded and collated by SEPA.
User Conflicts	Occupation of ocean space	Minimized utilization of surface water space		Area of sea surface allocated per tonne of production	National data centres, and licensing authorities.	Could be done now	Scotland – Current data readily available. Historical data may be more of a problem.

Proposal to initiate assessment and use of sustainability indicators for aquaculture

WGEIM 2007 developed a provisional framework for the development of sustainability indicators for aquaculture (Table 3.1). WGEIM 2008 continued discussion on this topic and noted that several schemes existed for assessment of potential indicators related to ecological quality. An example developed by ICES WGEICO is shown below (Table 3.2).

Table 3.2. ICES criteria for a good Ecological Quality metric (after Report of the ICES Advisory Committee on Ecosystems, 2001. ICES Cooperative Research Report 249: 75 pp.).

Criterion
a. Relatively easy to understand by non-scientists and those who will decide on their use
b. Sensitive to a manageable human activity
c. Relatively tightly linked in time to that activity
d. Easily and accurately measured, with a low error rate
e. Responsive primarily to a human activity, with low responsiveness to other causes of change
f. Measurable over a large proportion of the area to which the EcoQ metric is to apply
g. Based on an existing body or time-series of data to allow a realistic setting of objectives

WGEIM 2008 agreed that an initial attempt should be made intersessionally to apply some of the proposed indicators to salmon farming industries, initially in Scotland, Ireland and Canada. This exercise should demonstrate the potential utility of this approach, identify strengths/weaknesses/limitations therein and provide an indication of the effort required to collate and analyze the required information. Thus, the outputs may provide guidance on useful data gathering routes and potentially a template for future expansion to additional jurisdictions.

Many of the proposed indicators in Table 3.1 fall into the requirements identified in Table 3.2. Additionally, some of the proposed indicators can be coupled into convenient groupings, for example:

- a) Items 1 and 8 were related to allocation of resource (space) and impact on that resource;
- b) Items 6 and 7 were related to disease;
- c) Items 2 and 4 were related to nutrient utilization and release.

and data collected in support of one item will be a useful component of the paired item – thus, they will be treated together in this assessment. The outstanding items from Table 1 (3 – Genetic Interaction and 5 – Energy consumption) are considered beyond the scope of this initial assessment overview.

In order to undertake this type of assessment, there requires not only an information and data gathering exercise, but also a broader understanding of the specific definitions, usage and confidence/(un)certainly envelopes associated with each parameter within each jurisdiction.

In addition, reasonable agreement between each of the jurisdictions over which factors could be considered comparable will be necessary. For example – site/lease area may on face value appear to be a relatively simple and comparable parameter. But differences in the permit granting frameworks of each jurisdiction may result in substantially different lease areas for what may essentially be considered identical farms. Thus, an understanding of how lease areas are set in each jurisdiction will be required.

The outputs of these initial analyses will essentially be snap-shots of the sustainability indices identified in Table 3.1. At present it is unclear whether inter-jurisdictional comparisons of these data will be possible. The usefulness of these values will be seen when compared with historical data and/or future assessments. At that point, the direction of change (as indicated in Table 3.1) will become apparent and careful assessment of these values may provide insight into the relative sustainability of the industry.

4 ToR b) – to further investigate fouling hazards associated with the physical structures used in mariculture with a view to developing integrated pest management strategies (Leads Chris McKindsey, Thomas Landry, Canada)

Here, we define the types of information that are needed to develop an integrated pest management strategy (see Table 4.1 for an example). In the current text, we do not discuss information on mitigation methods, as this is covered in other texts (see ICES 2007, McKindsey *et al.*, 2007). Rather, we concentrate on studying the physical and biological factors that allow for the establishment and development of the communities in the first place. Knowledge of such information should (hopefully) lead to insights as to how infestations may be controlled or limited.

To illustrate the process, we outline a proposed joint Canada-Spain cooperative research programme to evaluate mechanisms that lead to the establishment and perpetuation of pest tunicate species, with an emphasis on *Ciona intestinalis* in Prince Edward Island, eastern Canada, and Galicia, Spain. In eastern Canada, particularly Prince Edward Island, the mussel aquaculture system has been ravaged by the appearance of 4 exotic tunicate species in the past decade. *Styela clava* was the first to be reported, in 1997. *Botryllus schlosseri* was reported in 2001, *Botrylloides violaceus* in 2002, and *C. intestinalis* in 2004. Of these, *S. clava* and *C. intestinalis*, both of which are solitary species (as opposed to *B. schlosseri* and *B. violaceus*, which are colonial species), are the species creating the greatest damage to the industry in eastern Canada. Some of these species (all except *C. intestinalis*) are also present and of concern in western Canada, as is the colonial tunicate *Didemnum vexillum*. These same species, as well as other tunicates (*Asciidiella aspersa* and *Phallusia mammillata*, both solitary tunicates) are also pests on the mussel rafts in the rías of northern Spain.

An examination of Table 4.1 will show that the two systems differ in a number of ways with respect to husbandry, physical conditions, the biology of species cultivated, and the biology of the pest species under consideration. With respect to husbandry, the Spanish mussel system is based on raft culture whereas the Canadian system is based on longline culture. In both systems, individual dropper lines are spaced by about 50 to 75 cm. Because of differing bathymetry, dropper lines in Spain are much longer than those in Canada (regulated to 20m in Spain and varying between ca. 2 to 5m in PEI). In Spain, dropper lines are hung from large rafts (ca. 20 × 25 m) and different parts of the rafts hold different age classes and/or species. Individual rafts are separated by about 100m and occupy significant but localized areas in the rías (tight but lumped spacing). In Canada, dropper lines are suspended by longlines some 60-100m long and which are spaced apart by ca. 5-10m, with farms also occupying significant but localized areas in embayments (tight but spread out spacing). The species cultivated also differ such that *Mytilus galloprovincialis* is cultured in Spain whereas *Mytilus edulis* is cultured in Canada. In Spain, socking is done throughout the year and spat is preferentially harvested from wild intertidal populations. In PEI, socking is done mostly in the fall using wild-caught (on collector lines) spat. Mussel

lines are routinely treated with line and other antifoulants to reduce the abundance of tunicates, starfish, and other foulers. In contrast, lines are rarely treated in Spain. Fallowing of sites is required in Spain whereas it is not in Canada.

Both systems are quite productive, with productivity based largely on upwelling in the northern Spanish rías and anthropogenic eutrophication in the PEI embayments. The northern rías in Spain are drowned river valleys that are relatively deep (ca. 25 m in culture areas) with strong ($> 1 \text{ m sec}^{-1}$) currents, relatively cool but stable temperatures, and mostly oceanic salinity. The embayments in PEI include coastal plain estuaries as well as lagoons that form behind barrier sandbars (barachois) on the Island's north shore and are typically fed by rivers at their heads, are fairly shallow ($< 7 \text{ m}$) and have comparatively weak current regimes, have greater temperature fluxes, and are less saline. Despite these differences, both systems are characterized by similar flushing times (2-7 days: Gregory *et al.*, 1993, Álvarez-Salgado & Gilcoto 2004, Grant *et al.*, 2005, Torres-López *et al.*, 2005).

The two systems also differ with respect to the biology of the species being cultured (*M. galloprovincialis* is cultured in Spain whereas *M. edulis* is cultured in PEI) and the pest species such that the growth rate of the former mussel is greater than that of the latter and the basic biology of *C. intestinalis* differs in that it is reproductive throughout the year in Spain but has seasonal reproduction in PEI. Other biological differences are also possible but are unknown.

Given the above, a number of factors may be responsible for the contrasting levels of infestation between eastern Canada and Spain. Among many, there is the possibility that hydrodynamic conditions alone or in concert with hydrodynamic-biological interactions create such differences. There is also the possibility that there is something intrinsically different with respect to the mussel lines themselves. Either differences in the mussels themselves and/or the communities associated with the mussels (in terms of diversity, trophic structure, etc.) may account for differences in pest loads. Alternatively, differences with respect to the tunicates themselves may account for differences in pest loads.

Below, we outline a series of studies that are being proposed to better understand the potential importance of the various factors outlined above to the establishment and perpetuation of *C. intestinalis* populations in mussel aquaculture in order to implement a logical integrated pest management strategy to control the abundance of the species.

Husbandry and environmental-level effects. Consideration of variations in husbandry and environmental factors between the two sights suggest the hypothesis that variations in the spatial configuration of farms and currents interact to create differences in *C. intestinalis* loads between the two locations. We suggest that optimal conditions for tunicate recruitment and fouling occur in PEI (low flushing, slow currents, and covering embayments with close-packed mussel lines) whereas the very localized nature of mussel culture in Spain coupled with good flushing and strong currents limits recruitment and fouling there.

To evaluate this hypothesis, we will model the potential dispersal of tunicate larvae under these two conditions based on a hydrodynamic model and including a variety of physical and biological parameters, including:

- the patency time for larvae (e.g., from an age of 1 to 2.5 days at 20°C);
- the effect of egg density;
- the effects of current speed on ability to recruit;

- the effects of current speed on ability to grow; and
- the effects of temperature and salinity on these parameters.

Although the patency and density information needed to construct this model are available (see Carver *et al.*, 2006 for a review), the information on settlement and growth under different current conditions is largely unknown. To this end, a research project is to begin in the summer of 2008 in PEI to evaluate these parameters. An initial generic model (i.e., not site-specific but rather with the general features of the culture sites with respect to depth, currents, flushing, spacing, etc) will be developed to evaluate whether this hypothesis is worthy of further evaluation before developing more complex models.

Evaluation of the biological information provided in Table 4.1 suggests further models to explain differences in *C. intestinalis* loads between the two systems such that there is something intrinsically different with respect to the mussel lines in the two systems. Either the mussels themselves are different in some way or else the associated communities may differ with respect to diversity, trophic structure, etc. Alternately, differences among locations may be due to variation in the biology of *C. intestinalis* itself between locations. A number of studies will be undertaken to evaluate these possibilities.

Mussel-level effects. That different species are farmed in the two countries suggests a series of mechanisms to explain differences in infestation levels. A number of factors will vary with respect to species-level effects. However, the identification of such differences is moot unless a difference is observed with respect to species-level susceptibility of the different species. To evaluate this, mussel socks composed of *M. edulis* will be compared to others of *M. galloprovincialis*, each from a number of sources, will be placed in a common garden experiment (an infested part of the rías) to evaluate whether there are species-level differences. [An attempt will be made to import mussels from Canada to Galicia for this experiment although we acknowledge that this may be blocked because of I&T regulations. If so, laboratory experiments will be undertaken to evaluate mussel species and population-specific (i.e., Canadian *M. edulis* vs. Spanish *M. edulis* and *M. galloprovincialis*) susceptibility to *C. intestinalis*.] Similarly, as mussel seed for socking is obtained from 2 sources in Galicia (harvested from intertidal sites or else wild-caught on suspended collectors), socks of *M. galloprovincialis* from both of these sources will be included in the analysis. Personal communications with Galician farmers suggest that wild-caught seed is of better quality (i.e., survivorship is greater). As *C. intestinalis* seems to mostly attach to the supporting structure rather than the tunicate itself in Galicia, in contrast to it readily attaching to mussels as it does in PEI, it is also possible that poor spat survivorship may result in greater areas of exposed mussel culture structure, leading to heightened densities of *C. intestinalis* on such mussel lines.

Other possibilities at the level of the mussels themselves include potential differences in genetics, physiology, behaviour, and biofilms on the surface of the different species. If differences in recruitment and/or tunicate loads are observed among treatments as outlined above, further studies and experiments will be undertaken to determine to evaluate these possibilities.

Tunicate-level effects. Differential ability to recruit and/or grow on shell surfaces between the different coasts of the Atlantic suggest that the *C. intestinalis* populations on the two coasts may differ genetically and in other ways. Thus, an initial study on the genetics of the two populations will be undertaken to determine how divergent the two populations are. If genetic differences are observed, laboratory experiments

will be undertaken to evaluate their growth and reproductive potential as well as their ability to recruit and grow on mussels. This information could also be used to refine the dispersal models outlined above.

Mussel community-level effects. There is little contemporary data with respect to the structure of mussel communities in aquaculture in the area of Galicia or PEI. Thus, a series of synoptic surveys (similar to those outlined by Arenas *et al.*, 2006) of the organisms associated with bivalve aquaculture, including both fouling organisms as well as those more loosely associated with the culture structures, including fish, shrimp, crabs, etc., will be done to better describe the structure of assemblages associated with the mussel aquaculture in the different sites. An exhaustive literature review will also be done to find similar data from these and other locations around the world. This data will then be analysed to seek trends in “susceptibility” of mussel communities to infestation by tunicates. If trends emerge, manipulative studies (i.e., modification of mussel sock community structure) will be done to evaluate the importance of this factor.

Table 4.1. 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 intestinalis* as a target species) to suggest insights into potential explanations for the observed differences in tunicate loads. See text for details.

Factor	Spain	Canada (PEI)
Husbandry		
• Farm structure		
• Type	- raft	- longline
• Spacing	- tight / clumped	- tight / spread
• Species farmed	- <i>M. galloprovincialis</i>	- <i>M. edulis</i>
• Socking management		
• Timing (seasonal / stage)	- continual	- fall socking
• Treatments	- no	- liming, etc
• Fallowing	- yes	- no
Environment		
• Food availability	- upwelling	- eutrophic
• Hydrodynamic regime	- deep, open	- shallow, closed
• Temperature	- stable	- variable
• Salinity	- stable	- stable
• Currents	- great	- low
Biology (cultured bivalve)		
• Basic biology	- <i>M. galloprovincialis</i>	- <i>M. edulis</i>
• Growth rate	- fast	- slower
• Recruitment	- ongoing	- seasonal
• Tolerances	- ?	- ?
• Other...	- ?	- ?
• Physiology	- ?	- ?
• Genetics	- ?	- ?
• Susceptibility to overgrowth	- ?	- ?
Biology (pest)		
• Basic biology		
• Recruitment	- continuous	- seasonal
• Tolerances	- ?	- ?
• Other...	- ?	- ?
• Physiology	- ?	- ?
• Genetics	- ?	- ?
Community interactions	- ?	- ?

4.1 References

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5 ToR c) – evaluation of the outputs of a number of integrated aquaculture (multi-trophic culture systems) projects including an commentary on the environmental and regulatory effects (Leads: Stephen Cross and Shawn Robinson)

Developed as a ToR in 2006, the ICES-WGEIM has documented that IMTA is being pursued, as pilot-scale research projects, in a number of locations among its member countries. Canada, in particular, is moving forward rapidly with the commercialization of IMTA with projects (linked with business development) occurring on both the Atlantic and the Pacific coasts. These initiatives are concurrently addressing system engineering, ecological balance, materials/energy flow, governance, as well as socio-economic aspects of this approach to multi-species aquaculture production.

The following is provided as a summary of the material provided to the Working Group as a basis for discussion.

5.1 Pacific Coast

The commercial development and testing of IMTA (or Sustainable Ecological Aquaculture = SEA-Systems) is being examined at a farm site that has received the first marine IMTA license for co-culture of a variety of species including a combination of macrophytes for the inorganic extractive component (*Laminaria*, *Porphyra*), shellfish and echinoderms for the organic extractive components (*Mytilus spp.*, *Patinpecten yesoensis*, *Crassostrea gigas*, *Stronglylocentrotus spp.*, *Parastichopus californicus*), and the single fed (finfish) component being sablefish (*Anoplopoma fimbria*).

A number of key points arose from discussions with emphasis on the following:

5.1.1 Regulatory Issues

The western Canada SEA-System development has shown that the existing policy and regulatory framework for aquaculture (both Provincial and Federal) has allowed for immediate inclusion of the multi-species, integrated approach to aquaculture. Treated as independent culture components, licensing and operational regulations (including environmental monitoring, food safety programmes, HACCP, etc.) are applied to classes of species considered for the SEA-System, i.e., finfish, shellfish, aquatic plants. As IMTA (SEA) systems become an attractive business option for aquaculture it is recognized that the internal review process for site applications will need to become more efficient, treating these *production systems* holistically rather than as a combination of reviews that are currently designed for the individual components. Nevertheless, Canadian regulatory agencies agree that current regulations address all issue of environment and seafood quality/safety, and have indicated where industry should focus development of IMTA Best Management Practices (BMP's) to satisfy these requirements.

5.1.2 Economic Benefits

While the selection of species for an IMTA system is based on an ecological design premise, and one that addresses the issue of organic wastes that are generated and lost to the environment from an open netcage fish culture system, the specific selection of species must consider the economic benefits for this shift to a more complex food production model. The commercial development on the Canadian west coast is based on an 'intensive' IMTA design, modifying the standard steel netcage system for finfish production to incorporate shellfish, kelps, and echinoderms into a system that will provide a significant economic incentive for future consideration of IMTA as

an aquatic food production model. Given staggered production cycles, and using salmon rather than sablefish in the projected farm-gate revenues for this system, there is an estimated 45% increase in annual production revenue anticipated from this system design.

Clear economic benefit to the development of IMTA provides a business incentive that is expected to stimulate innovation and expansion for this sector over the next few years.

5.2 East Coast

The IMTA program on the east coast of Canada is centered in the Bay of Fundy and has been operating for 7 years since 2001. It started as an academic research program (AQUANet) and has now transitioned into a scientifically-based project for commercial development. The IMTA system was initially designed around 3 species: a fed species: Atlantic salmon (*Salmo salar*), an organic extractive species: the blue mussel (*Mytilus edulis* and *M. trossulus*) and an inorganic extractive species: kelps (*Sacharina latissima* and *Alaria esculenta*). The work involves direct field-based trials with the industry partners: Cooke Aquaculture Inc and Acadian Seaplants Ltd, an academic institution: the University of New Brunswick and the DFO research laboratory the St. Andrews Biological Station.

5.2.1 Regulatory Issues

The regulatory climate for IMTA in eastern Canada is gradually improving as the managers and the regulators become more familiar with the IMTA concept. The general feeling is that IMTA has several benefits and that the practice may provide for better environmental sustainability. This acceptance is happening at both the national and the provincial levels. Currently, at the regional scale, New Brunswick is adapting their policies to incorporate the IMTA concept and have begun to create a draft (January 2008) for licensing criteria for IMTA in the Bay of Fundy to hand out to industry. Newfoundland and Labrador Dept. Fisheries and Aquaculture (NLDAFA) is in the process of adapting their regulatory measures for aquaculture to encompass IMTA. There are currently 3 sets of NLDAFA policies that have bearing on the adoption of IMTA, the most critical one is a limitation of a single species per site. Nova Scotia and Prince Edward Island are still evaluating whether to adopt IMTA as a development policy, although industry in Nova Scotia is actively lobbying to adopt the concept.

In the national headquarters region, Ottawa, the recognition of IMTA as a policy and regulatory item is also on the increase. As a result, a review of existing policies that could potentially impact IMTA development has been done (Stetchey, 2007) and a research network to address some of the issues is being developed.

5.2.2 Economics

The economic benefits of IMTA concepts being incorporated into salmon aquaculture sites appear to be very favourable. Industry requirements, based on industry interviews, suggest that any new species that could be incorporated into an aquaculture site must generate revenues in the order of \$50,000 or more. Based on a current model of 6 mussel rafts and 4 kelp rafts incorporated with a salmon site, the gross additional revenue is predicted to be close to an order of magnitude greater than the industry threshold. This potential revenue stream has played a large role in stimulating industry's desire to adopt IMTA techniques.

Marketing research has shown that there seems to a potential of increasing the market price of mussels and thereby increasing the revenue to the growers. This is based on large market surveys of New York as well as more localized surveys in eastern Canada. Increasing the economic returns to the grower has a number of implications for environmental interactions. Increased prices imply higher levels of quality. To achieve the highest quality levels, and subsequently process, mussels will have to be produced in a manner that will not affect their meat quality or the environment in which they are grown.

5.2.3 Disease and Parasites

Diseases and parasites are often one of the first concerns that are raised in the implementation of IMTA. It is thought the addition of additional species may help to either harbour or transmit diseases to the primary fed crop (e.g. salmon). Some of these objections are the result of a monoculture perspective. In actual fact, if the IMTA species used are endemic to the area, then they are usually already present on the site in close proximity to the animals as part of the fouling community. Therefore, it is not a case of presence or absence, but rather one of dose threshold and whether or not the species are capable of retaining or transmitting the disease. For one disease, Infectious Salmon Anemia (ISA), the blue mussel (*Mytilus edulis*) has been shown to destroy the virus (Skar and Mortensen, 2007). This has been verified in subsequent experiments (S. Robinson et al, in prep.). There is also potential for positive interactions to occur for parasites. On salmon the sea louse (species?) can cause significant losses for the salmon farming industry. Since mussels have been documented to eat nauplii, it may be possible for mussels to reduce the infection of salmon by sea lice by the incorporation of mussels into the salmon production site.

5.2.4 Seed Limitation and Potential Sources

As new species or “biofilters” are incorporated into an IMTA site providing both environmental services and an additional revenue stream for industry, there will be a need for “seed stock”. While a few species may be amenable to wild collection, the majority will need to be produced from a hatchery. At present, there are very few hatcheries available to produce the required biofilters and in many cases the technical and scientific knowledge is not available. The need to address this issue is relatively short-term since, if there is a requirement for a biofilter to fit a particular niche, then industry will want to adopt that particular biofilter as they scale up their IMTA systems. An example of this would be the assimilation and subsequent extraction of particulate organic nutrients released from salmon open-case feeding operations. Detritivores (e.g. worms, sea cucumbers etc.) are the most likely candidates, but there are no hatcheries producing these organisms at the present time in Canada. While there are fisheries for these species, juveniles are almost impossible to harvest at the needed densities and the socio-political issues would be a significant impediment.

6 ToR d) – Review the use of seed stock quality criteria in mariculture and their applications in term of ecological performance (Lead: Thomas Landry, Alain Bodoy)

The quest by humans to domesticate animal and plant species to improve food production by means of care, feeding and breeding has been ongoing for several centuries. In the terrestrial environment, over 90% of the species used by humans for food are considered to be domesticated, while in the aquatic environment the ratio is estimated at 3%. This ratio, however, is on the rise with the aim of increasing the benefits

while minimizing the risk associated with domestication of aquatic species for farming purposes. One of the key areas of domesticating aquaculture species is improving seed quality. On the benefit side, the emphasis is to maximize profitability by improving productivity in terms of growth, survival and product quality. On the risk side, the main issue has been the potential impacts of escapees on wild populations. The escapee issue has been reviewed, particularly for salmonid and non-salmonid fish species, in previous reports of the WGEIM. To date, however, the issue of environmental performance has been largely ignored, despite its potentially critical role in mollusc aquaculture. In respect with seed quality, environmental performance is viewed as including the size of the ecological footprint, the quantitative fluxes of carbon and nitrogen and the potential changes in biodiversity which are related to the activity. Here, due to the high degree of interaction between cultured species and the environment, the environmental performance of domesticated molluscan species could present risks and benefits that would match or exceed those of escapees and productivity. The aim of this paper will be to investigate the option of balancing the risk and benefits of integrating environment performance (footprint) in the development of seed quality criteria with economic performance (profitability). Environmental performance will be divided in two categories i) intake and ii) output.

6.1 Intake

Starting with a common denominator, oxygen intake from finfish, shellfish and plant species can vary considerably in relation to physiological fitness. This feature can easily be managed through the selection of seed, but may have some impact on the profitability of aquaculture operation, mainly in terms of the production cycle. On the other hand, seeking a more balanced approach may presents benefits on the footprint side.

For mollusc and plant species, intakes have been focused on organic matter, including plankton, and nutrients. Here again, reducing the intake rate of cultured species may lead to lower profitability in relation to production cycle. However, it could be balanced with the increase production in biomass within the same production area.

6.2 Output

The issue of bio-deposition has received the bulk of the attention in terms of biological output from aquaculture in general. Nutrient output has also received considerable attention, both for finfish and shellfish. On the other hand, reproductive outputs have received very limited attention. The management of these emissions, through seed quality, could not only improve the acceptability of the aquaculture industry, but could in fact contribute to their profitability.

WGEIM recommend that this ToR be continued to further expand this theme with the view to producing a complete text in 2009.

7 ToR e) – Joint Meeting between ICES-WGEIM and PICES-Aquaculture Group

A large portion of the meeting was given over to a joint meeting between WGEIM and a group of like-minded scientists (scientists with interest in Aquaculture research and development) originating from the North Pacific Marine Science Sphere (PICES). A number of presentations were given on a range of topics, based broadly upon existing or past ToRs of WGEIM, which were followed discussions.

7.1 Risk Assessment relating to Aquaculture activities.

7.1.1 Overview of Risk Assessment Work of WGEIM and FAO-GESAMP WG31–Edward Black

Dr. Black presented an overview of a term of reference recently completed by WGEIM on risk assessment related to mariculture. The talk summarized the basic tenets of the assessment of risk and outlined a template for assessing risk that has been developed in conjunction with WGEIM and published by the FAO (*GESAMP Reports and Studies 76* at <http://www.fao.org/fishery/publications/en>). A number of points were discussed that are summarised under the headings below.

Assessment protocols:

- Geographic scale of the analysis needs to reflect ecological functional units that respond as a unit. A cove with low residence time may not qualify, but a water body with a longer residence time may be a functional ecological unit.
- The prediction of the level of likely change can be based on correlative or mechanistic prediction protocols. Of course correlative predictors have a higher degree of uncertainty and more of that uncertainty arises from a lack of statistical accuracy in the prediction. As predictors mature generally they move from correlative predictors to predictors based on our understanding of the underlying mechanism of the phenomenon. As the mechanistic predictor become better the error becomes less and less an issue of accuracy based error and more a problem of precision based errors.

Communication / Trust

- Prior development of aquaculture can impact on the effectiveness of risk communication as a consequence of pre-conceived notions relating to the activities.
- Open and transparent peer reviews can be valuable in building trust in the scientific analysis even if in situations where different parties may not agree on the significance of the science findings.
- Persons inadvertently or for reasons of effective discussions (group size) are not physically included in discussion can form focus for development of contrary opinions and call into question the value of management based on the risk assessment. Instruction on how to mitigate against the development of such a situation would be useful.

Management System

- There is a clear need to identify roles and responsibilities of participants in a risk analysis.
- Scientist must be more aware of the limits of science (measure / predict) and recognize that managers and the public are the authorities for determining values issues.
- Need to recognize that values vary between communities. There may be a number of different value systems (represented by different communities) within the boundaries of a water body. There is a need to develop management tools to integrate local and remote urban values into determination of what is valued ecosystem components to be protected and what constitutes an acceptable level of change

A number of future steps were discussed which may be used to assess the comparison of effectiveness of governance process from application to start of culture activities and of subsequent monitoring programs. The identification of relevant monitoring indicators is important and mechanisms to compare their effectiveness and utility should be identified.

7.2 Fouling hazards associated with the physical structures used in mariculture with a view to developing integrated pest management strategies – Chris McKindsey

Structure associated with mariculture activities can provide considerable surface area for colonisation of species not typically found in the culture area. This is presumably due to the increased habitat complexity and appropriate substrate for epifaunal organisms. In addition to the potential to provide a pathway for the introduction of an exotic nuisance species to a system, additional problems encountered are those associated with the management of the nuisance to reduce the impact on the culture activity. This ToR will highlight existing examples and will address the management implications and potential mitigation strategies. Focus will be provided on basic information required to understand controlling process and factors that might inform potential mitigation strategies. It is apparent that this issue has particular relevance on the East Coast of Canada and in Spain. Further details are provided in ToR b, above.

7.3 Seed stock quality criteria in mariculture

7.3.1 Shellfish seed stock quality criteria in mariculture and their applications in term of ecological performance – Thomas Landry

For economical reasons, mariculture development is based on the continuous improvement of seed and fry, being wild or produced in hatcheries. How these improvements, particularly those which contribute to increase the physiological fitness and food efficiency may impact the use of the resources from the natural environment is a question of high relevance for decision making. The trade off between the economical and the ecological performance of mariculture, and consequently the regulations (e.g. licensing) to follow, is consistent with the objectives of sustainability and responsible natural resources management. The aim of this work will be to review the use of seed stock quality criteria in mariculture and their applications in term of ecological performance. This subject is dealt within more detail below in ToR d, above.

7.3.2 Risk and risk management for seed production for marine fish raised in open ocean aquaculture- Michael B. Rust

For open ocean aquaculture of marine fish, the provision of seed occurs externally to the actual fish culture operation. How such external activities are conducted and applied determines the potential ecological impact for the industry as a whole. The identification and characterization of hazards and risks are the first steps in determining what risk management strategies might be the most productive in developing supplies of seed for offshore aquaculture that are low risk and will be stable and dependable over the long run. In some cases a complete risk assessment may not be necessary to guide decisions associated with long term risk management. For each risk, the WHO risk assessment framework may be applied to focus research and development on strategies that could be used to reduce or eliminate risk. In most cases, multiple options exist for risk reduction, however I suggest that risk management strategies that improve economic gain and reduce or eliminate multiple ecological

risks, are preferred and have a much higher chance of resulting in meaningful improvements. Furthermore, strategies which allow for improvement, or change over the long term, provide more flexible and ultimately sustainable solutions. Finally, the solution of one risk may create or eliminate other risks which should be taken in to account in decisions among competing risk reduction strategies. In most cases, research is needed to develop better risk management strategies. Up-front costs associated with research, development and implementation often limit application of risk management strategies to industries large enough to afford such costs even if there are long-term economic benefits associated to doing this for small but growing industries. This is especially true when governments do not fund such research and development.

Potential up-stream ecological impacts associated with seed from culture of marine fish include over-fishing due to demand for wild juveniles for grow-out (Nash *et al.*, 2005). Stated as a simple equation, risk of over-fishing (R) is a function of fisheries management (M) with the effectiveness of management subject to demand [$R = f(M)$]. On some low scale of harvest (low demand), fisheries management has been shown to be effective, however management can only produce some fraction of what exists naturally, and wild fisheries are not able to increase production beyond naturally set limits. At harvest levels higher than a stock can recover from, over-fishing occurs. When there is a high demand, fisheries management becomes increasingly difficult so alternatives need to be found that reduce or eliminate demand for wild seed used in aquaculture. Management to reduce the risk of over-fishing due to seed is the development of hatcheries for seed production. Complete replacement leads to elimination of the risk due to activities associated with offshore aquaculture and partial replacement leads to demand reduction potentially to sustainable levels at least until the industry grows again. In addition, hatcheries can provide economic benefits (in the way of lower prices and better quality) and thus have a greater potential for adoption by industry once a critical size of an industry is reached.

Downstream risks associated with seed production are associated with the potential ecological and genetic impacts of escapes on conspecific wild stocks if the cultured fish is native or ecological impacts on native species if the escapees are non-native. For the sake of this paper I will only deal with the first risk. Risk (R) associated with the escape of a native species is a function of the number of escapes relative to the number of wild conspecifics (P_e/P_w), the differences in genetic structure between the wild and escaped organisms (ΔG) and the fitness (F_e) of the escapees to reproduce in the wild [$R = \text{function of } (P_e/P_w)(\Delta G)(F_e)$]. Risk associated with escapes can be managed at the hatchery by several strategies. For example, either raising fish with the same genetic make-up as wild stocks where $\Delta G = 0$, or by domestication of the farmed species which reduces escapees' fitness (F_e) in the wild. In this case, economic gains would favour domestication and not maintaining a wild stock genotype. Risk can also be reduced by raising sterile fish (where $F_e = 0$) which may or may not be economically beneficial, or by maintaining a low number of escapes (for example by better engineering or management practices) relative to the size of the wild population. Note that the converse is also a possible strategy, risk can be reduced by maintaining wild stocks at high levels relative to the number of escapes. This may be addressed by industry by raising a portion of the species they produce under stock enhancement protocols for release (likely to have negative economic implications). An approach that combines several of these strategies may be the most effective.

Risks can be interactive and need to be viewed as a set for a given activity to guide management and research. Often new risks can be created when a different risk is

solved, or the choice of a risk management strategy that reduces or eliminates one risk may or may not also reduce or eliminate another risk. For example, the development of a hatchery to reduce the risk of over-fishing to provide seed, potentially creates the genetic risk of escaped fish on their wild conspecifics. If wild fish were used, then $\Delta G = 0$ and the genetic risk from escapees would not exist. This has led some to call for only using local unselected wild fish as broodstock for hatcheries producing seed for offshore aquaculture and actively maintaining a wild-like genetic make-up in the hatchery. However to do this would forgo the positive ecological risk reduction that selective breeding can produce in terms of seed that uses feed resources more efficiently, that makes better use of alternative feedstuffs, has better disease resistance and so on. Maintaining a wild genotype for fish used in offshore aquaculture would also forgo economic gains and puts environmental and economic goals at odds, reducing the chance for adoption and meaningful environmental risk reduction.

Governments can create win-win situations by fostering research and development where ecological risk management and economic gains are in line and both considered. In the case of seed production, this may include development hatcheries with associated selective breeding programs and methods to economically sterilize fish for new and existing marine fish industries. Governments can hasten and improve the potential for the adoption of preferred risk management strategies by first identifying those strategies that provide the best overall options and then by funding the up-front research and development costs to put those practices in place.

7.4 References

Nash, C. E., Burbridge, P. R., Volkman, J. K. (eds.) 2005. [Guidelines for ecological risk assessment of marine fish aquaculture](#). U.S. Dept. of Commerce, NOAA Tech. Memo., NMFS-NWFSC-71, 90 p.

7.5 An overview examples of sustainability indices proposed for mariculture activities:

7.5.1 Three EU projects relating to sustainable Aquaculture – Alain Bodoy

Three projects are on-going relating to the development and identification of appropriate sustainability indicators in Aquaculture. Ecosystem Approach to Sustainable Aquaculture (ECASA) identified a framework for an 'ecosystem approach' within which a number of impact indicators could be selected and combined to monitoring the effects of mariculture on marine systems. The project identified a multi-step process, whereby suitable indicators might be identified, i.e., Recommendation from project partners, Evaluation of indicators, Field-testing indicators, followed by stakeholder comments. A large number of impact indicators were identified were further tested in field situations. The consensus was that indicators were not good enough to indicate sustainability alone because of the inability to predict impacts; however, when used in conjunction with modelling initiatives they can present a useful step towards identifying and developing sustainability metrics. A key deliverable of the project is the development of the ECASA toolbox (<http://www.ecasatoolbox.org.uk/>). The ECASA toolbox is a virtual toolbox, which contains 'tools' to aid owners and operators of fin-fish and shell-fish farms in selecting farm sites, and operating farms, so as to minimize environmental impact and ensure the sustainability of sites and water bodies for aquaculture. It is expected that some tools can also be used by public environment managers to help maintain environmental quality. CONSENSUS is an EU funded coordinated action programme

that provided an interface for a number of different stakeholders in order to facilitate the development of protocols relating to the production of aquaculture in a sustainable fashion. The programme also provided a forum with the goal of providing balanced information for consumers on the benefits of aquaculture produced foods. Evaluation of Sustainable Aquaculture Production Systems (EVAD) is a broadly similar project with the goal of proposing a generic method of analysis of the development factors of aquaculture in order to evaluate its sustainability. A crucial aspect of these three projects is the selection of pertinent indicators (consistent with the broadly accepted criteria of indicator utility) with which to assess sustainability. As yet this goal has not been fully achieved. Notwithstanding this, a crucial aspect has been realised from these projects and that is the importance of clear and concise presentation of science underlying the management of aquaculture activities in the marine environment. This communication cannot be understated and helps makes the management actions more understandable and acceptable to stakeholders.

7.5.2 Sustainability Indicators for Aquaculture – Katsuyuki Abo

Japan have been assessing aquaculture environment under “the law to ensure sustainable aquaculture production” in Japan. In this law, environmental criteria were determined by using three indicators; dissolved oxygen, sulfide content and benthos. In addition, now we are exploring more applicable indices (macrofaunal community, topographical indices, waste feed and etc). The indices are “impact indicators” rather than “sustainability indicators”. Estimating the impact and predicting the change of environment are necessary to discuss the sustainability. In terms of estimation and prediction, numerical modeling is the most appropriate tool to assess the sustainability. We developed variety of models to assess the environment and to evaluate the indicators. Models are useful only after validation; therefore field investigation and monitoring are important as well as modeling itself.

7.5.3 Towards sustainable Aquaculture in Korea - Lim Hyun Jung

Korean aquaculture productivity is decreasing due to various diseases and repeated harmful algal blooms. Therefore efforts have been made, since the late 1990's, to manage the environment for the sustainable development of aquaculture.

The establishment of indicators for sustainable aquaculture involves the production of a series of integrated maps on regional scales (marine environment level) which represent the levels of water, condition of water and sediment, biomass (phytoplankton, zooplankton and benthos) and appearance rate of contamination indicator species (e.g. starfish) since 2006. That can help to evaluate the ecosystem stability of marine environment in specific areas. Government and aquaculturist can decide aquaculture capacity and species on the base of the outputs of these integrated models.

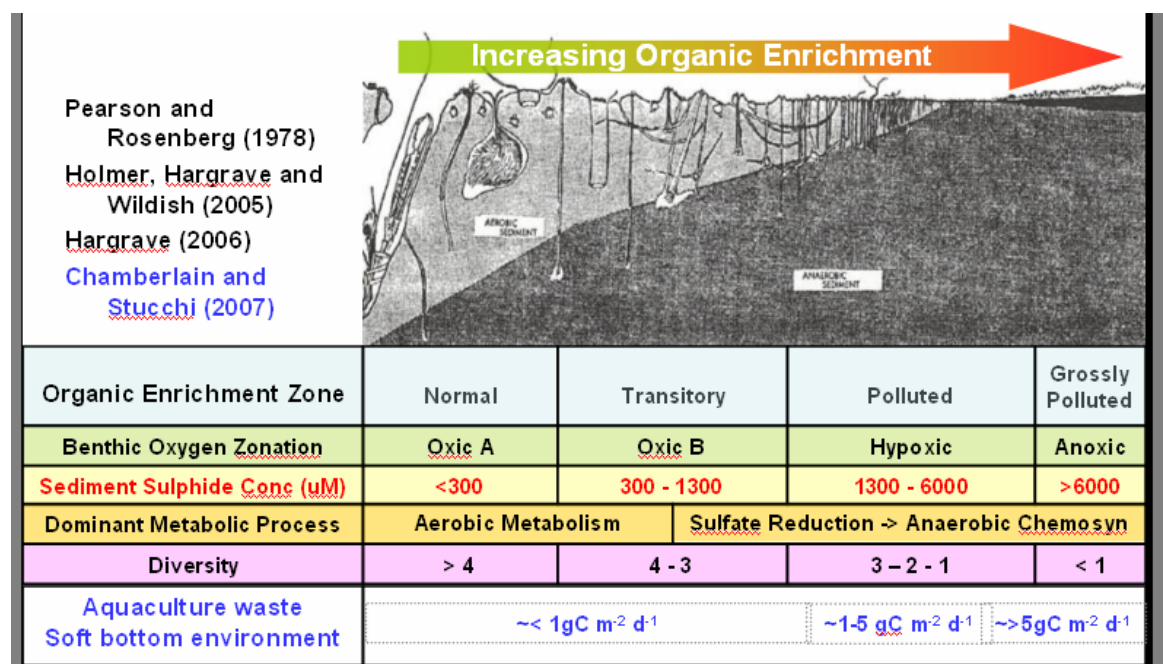
In addition, Korea are also are developing the technology of fisheriesstock enhancement to include the release of hatchery seed and its subsequent management through evaluation of success. The species currently being cultured are abalone, sea cucumber, sea bream, flounder and scallop

7.5.4 Use of sediment sulphide concentration as an indicator of benthic effects of aquaculture operations – a discussion on measurements and model predictions - Jon Chamberlain

Numerous organic enrichment classification systems have been proposed to quantify the scale and effect of marine cage finfish farm operations on the ‘health’ status of

proximal benthic conditions. Generally, these have been based on changes to the benthic infaunal community structure and/or sediment geotechnical characteristics. One relatively simple and cost-effective approach, which has been used at finfish farms in British Columbia for a number of years, is the measurement of dissolved sulphide concentrations in the sediment pore-water. This technique is applicable only to soft sedimentary environments from which relatively undisturbed samples of the seabed may be obtained using benthic grabs or cores. Classification of hard bottom substrates requires alternate methodologies that are not as well developed (e.g. video transects).

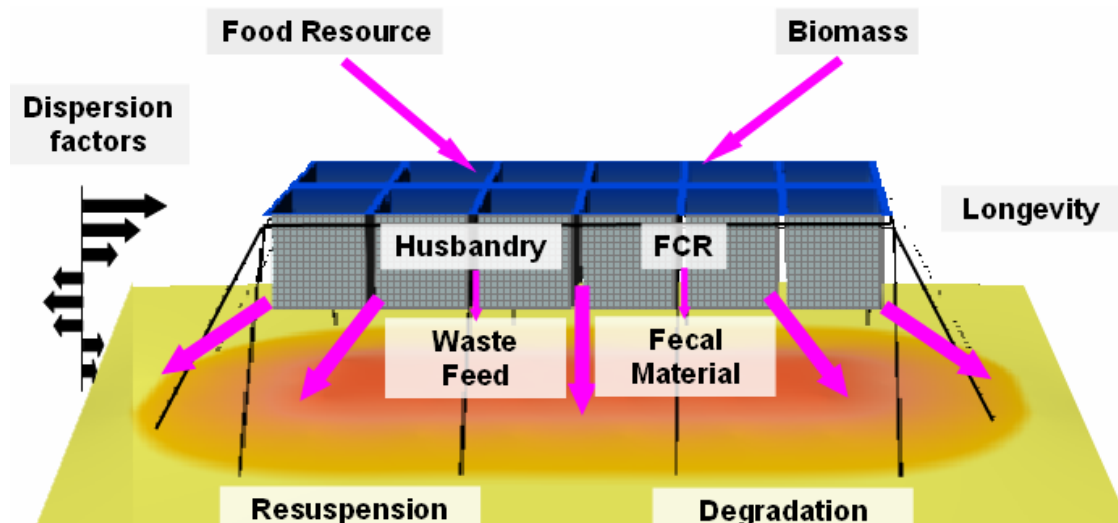
Although specific concentrations of sediment sulphide have not been assigned absolute thresholds in terms of benthic degradation – there is general consensus that increasing concentrations are aligned with deteriorating benthic conditions.



The results of routine monitoring of seabed conditions around finfish farm sites in B.C. between 2000 and 2005 revealed that over 50% of the surveys conducted at sites located in soft bottom environments had sediment sulphide concentrations that aligned with hypoxic and/or anoxic benthic status.

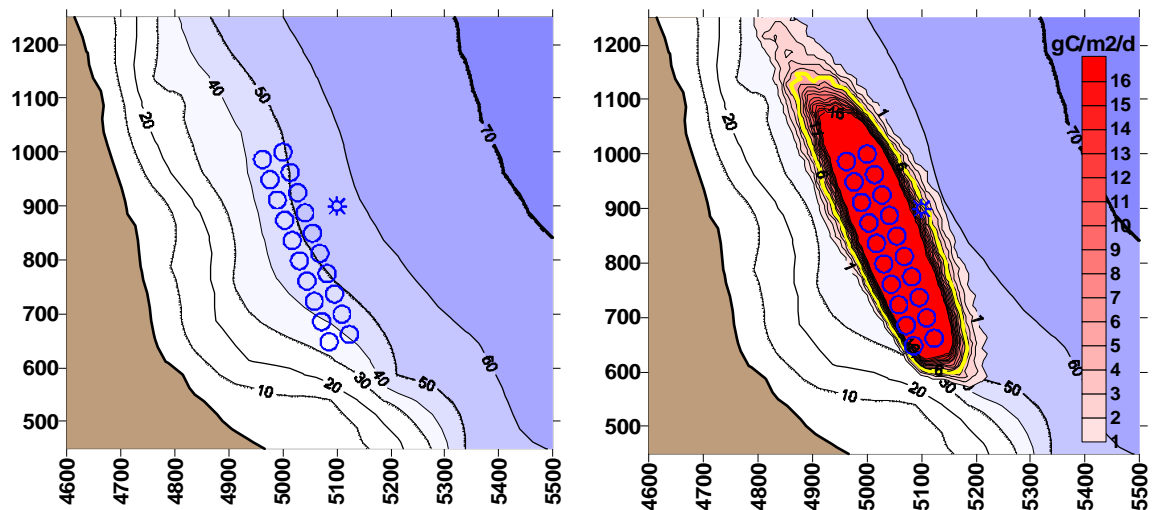
In addition to the development of monitoring tools, there has been a pressing need to develop models to predict the benthic effects of aquaculture operations. Indeed, the DFO Centre for Integrated Aquaculture Science (CIAS) currently identifies one of its top research priorities is the development of tools (i.e. models) that can be used to predict ecosystem effects from aquaculture operations, and to have these tools linked to scientifically sound sampling and monitoring regimes that are based on appropriate indicators and thresholds of ecosystem change.

The current status of development and application of such models delivers science support for ecosystem based management, with the credibility of peer reviewed publications, and an objective, transparent and consistent risk assessment and decision making framework that can be applied to both existing and future fish farm developments.



A major component of the above is the application of the aquaculture waste particle tracking model DEPOMOD to the Canadian environment, simulating the increased deposition of waste material from marine cage finfish farms onto the proximal benthic environment and predicting the potential nature and scale of biological and chemical effects. The model simulates and characterizes many of the important processes that act on and define the waste material settling through the water column and depositing on the seabed. In addition, research is currently underway in both Scotland and Canada to better characterize and simulate processes acting on the waste material post-deposition (e.g. resuspension, degradation). At present, these modeling techniques are applicable to soft sedimentary environments only. Development of methodologies to apply such models to hard substrate environments are still in the early stages.

The model requires site specific information regarding the location of net pens, seabed bathymetry, and the measured current speed and direction at different levels in the water column (this information is used to create the model domain seen below left). Data on the biomass of fish and/or feed input to the site for the modelled period are required. Using the above information together with other predetermined parameters, the model is run and predictions of the locations, areal extent and scale of flux of waste material to the seabed are calculated. The output of the model can be plotted as seen below right – in this case the model has been parameterized to predict the flux of carbon in $\text{g/m}^2/\text{d}$.



Plot of typical DEPOMOD output showing (left) the location of cages and bathymetry (all scales in metres) and (right) predicted footprint of deposition in g Carbon/m²/d simulating the farm site at peak production. The yellow line indicates the predicted 5gC/m²/d boundary currently used as an Authorization threshold in Pacific Region.

In the Pacific Region, DEPOMOD is used within a risk based management framework as an information tool to provide predictions on the potential nature and scale of effect of new or amended finfish farm operations. Model outputs are used in conjunction with other information sources to assess the likelihood of a Harmful Alteration, Disruption or Destruction (HADD) resulting from aquaculture operations and to delineate areas potentially subject to an Authorization under the *Fisheries Act*. Research in Pacific Region has identified that a predicted flux of between 1 and 5 g Carbon/m²/d on soft bottom environments aligns with the transition from oxic to hypoxic/anoxic benthic conditions (see table) and the creation of undesirable environments that would be of concern to DFO Habitat Management.

7.5.5 Evaluation of the outputs of a number of integrated aquaculture(multi-trophic culture systems) projects including an commentary on the environmental and regulatory effects – Stephen Cross and Shawn Robinson.

Developed as a ToR in 2006, the ICES-WGEIM has documented that IMTA is being pursued, as pilot-scale research projects, in a number of locations among its member countries. Canada, in particular, is moving forward rapidly with the commercialization of IMTA with projects (linked with business development) occurring on both the Atlantic and the Pacific coasts. These initiatives are concurrently addressing system engineering, ecological balance, materials/energy flow, governance, as well as socio-economic aspects of this approach to multi-species aquaculture production. Further progress is provided in ToR c, above.

An additional presentation was made on Thursday by Charles Yarish detailing the current state of play regarding seaweed aquaculture and is summarized as an abstract in Annex 4.

8 WGEIM response to the Draft ICES Science Plan

WGEIM had the opportunity to review the Draft ICES Science Plan (dated 22 February 2008). The group considered the plan from a number of perspectives: the broad aims/goals of the plan, specific themes highlighted in the plans and how the plan interacts with research on aquaculture systems currently being conducted by ICES members and others.

One of the two goals emanating from the ICES Strategic Plan, that govern the development of the Science Plan states that “a programme of science” should be planned “in partnership with member countries to deliver the needs to customers and stakeholders”. It would be informative if the document specifically identified the stakeholders and customers in question as well as how ICES proposes to plan for these partnerships and determine the needs of the member countries.

The plan introduces a number of new sectoral themes that will govern a number of ‘research’ activities that ICES will conduct. ICES research role is specifically dealt with in Section 7 and while the title indicates a coordination role that ICES is clearly in a position to carry out, the text suggests that it would be involved in more practical aspects of research, which ICES is not in a realistic position to conduct, in the strict sense of the word. In addition, the focus upon such a research role could run the risk of alienating individuals from some member countries (who involve themselves in a largely voluntary capacity) as they might not be eligible for such funding either as project leads or partners (e.g. scientists from North America are not easily funded through the EU).

The major headings require some introductory text in order to contextualise the specific themes discussed. In addition, ICES should consider replacing the term ‘impact’ in the title of some of the themes with a word that allows a broader consideration of the issues. While it is understood that both positive and negative impacts might be considered; the term ‘impacts’ has largely negative connotations and as a consequence the group recommends the use of the term ‘interactions’ instead. This will allow consideration of positive aspects relating to the research theme and also recommend a series of solutions to potential problems that might be encountered. For example, in Section 5.2.5 a responsible mitigation solution to some of the issues presented by traditional mariculture activities is the development of Integrated Multi-trophic Aquaculture (IMTA) and an Ecosystem Approach to Aquaculture, now a major focus of the FAO. IMTA incorporates an understanding of ecosystem function and presents itself as a mitigation measure to reduce the impacts of a number of aquaculture activities while at the same time increasing the production and success of such enterprises.

It is important to point out that the coastal zone habitat (Section 5.1.3) is equally as important to mariculture activities (even more so in certain jurisdictions) than to commercial fish production.

The broad theme 5.2 ‘Understanding of human impacts on ecosystems’, should consider these impacts in light of the how humans influence the functioning of ecosystem. This generalisation could be used to introduce the overall theme. One obvious omission from this theme is the interactions of fishing activities with marine ecosystems.

The framework presented in Section 6 of the Plan that introduces the Ecosystem Approach to Management is confused and incomplete. There is little indication that this

is the framework to which ICES operates and more importantly, the framework does not appear to address a critical factor that governs the management of marine ecosystems i.e. an understanding of ecosystem function.

Over the history of WGEIM, the group has provided advice, specifically in relation to mariculture, under a number of the headings considered in the framework on advisory needs presented in Table 2 of the Plan. The table appears to under-represent this level of activity and advice. In addition, we have previously highlighted the need for ICES to develop expertise in socio-economics in order to provide more complete and comprehensive advice and understanding of the role of mariculture in the marine environment. It is important to point out that such socio-economic expertise would likely be useful to those advising on capture fisheries as well.

WGEIM (2007) reviewed the work carried out by the group since the last Plan was adopted and considered how the work fit with the plan. It was generally concluded that the topics covered by the group were consistent with the plan on a number of different levels. In addition, the group considered emerging issues in relation to mariculture and examined how they were consistent with earlier drafts of the science plan. The results are presented in the table below (Table 8.1) and highlight how the emerging issues relating to mariculture are consistent with many of the themes proposed in the Science Plan.

It is with some disappointment, to the WGEIM group reviewing the plan, that mariculture is not prioritised to a greater extent. The first indication that mariculture is an issue is at item 16 and only that it presents a problem. This is surprising with the emphasis that international organisations, such as FAO, have placed on the role of aquaculture to provide the increased food and economic production required by world societies, particularly the rural coastal regions. Many countries are dealing with numerous social and management issues regarding current aquaculture systems based on perceived negative interactions with the marine environment, but are still planning on aquaculture contributing to local economies, be it marine or freshwater. The FAO has predicted that aquaculture will continue to grow for the next 25 years while capture fisheries will remain relatively constant, if not decrease. As a consequence, managers and scientists will be presented with numerous challenges to accommodate, in a sustainable fashion, these potential increases. It is important to point out that within the ICES community there is considerable expertise relevant to mariculture and that this expertise goes beyond those groups overseen by the Mariculture Committee, e.g. WGHABD under OCC. ICES expertise has advised on numerous regulatory issues in the past. It is the view of WGEIM that the organisation can position itself to have a major input in addressing future challenges to ensure sustainable aquaculture.

While it is appreciated that mariculture may be inadvertently considered under a number of themes already proposed within the draft Science Plan, the group strongly feels, in light of the comments above, that it merits more explicit attention in the future science direction of ICES.

Table 8.1. The table highlights a number of emerging issues relating to aquaculture identified by the group and relates them to those action points plan in what was then the existing plan as well as the proposed goals identified in the draft presented in 2007. Broad themes for WGEIM are: MSP – Marine Spatial Planning; SA – Sustainability of Activity; CC - Climate Change. (Extracted from WGEIM 2007)

Emerging issues relating to Environmental interactions of Mariculture	Relevant Action Points ICES Action Plan 2003-2007	Relevant Goals from Draft ICES Action Plan	Links to Broad Themes Relevant to WGEIM
Integrated multi-trophic aquaculture systems	2.6; 2.12; 3.10; 3.11	Goal 1	MSP, SA
Influence of Climate Change on mariculture systems	1.3; 1.6; 1.10; 2.2	Goal 1	CC
The application of Risk Analysis to new mariculture species or practices	2.5; 2.6; 3.3; 4.6; 4.7	Goal 1 & 3	SA
Deep water open ocean aquaculture	3.10; 3.11; 3.12	Goal 1	MSP, SA
Management strategies for disease, pest and predators treatments in mariculture settings with special attention on ecosystem interactions	1.2; 1.3; 2.2; 3.6	Goal 1	SA, MSP, CC
The interaction of mariculture and commercial fisheries.	2.2; 3.2; 3.12; 4.15	Goal 1 & 3	MSP, SA, CC
Review of quality criteria of seed stocks used in mariculture	1.2; 1.3; 2.2; 3.2	Goal 1	SA
Interactions between conservation and mariculture objectives	1.10; 1.11; 2.2; 3.2; 4.14; 4.15	Goal 1 & 3	MSP, SA,

Recommendation: WGEIM recommends that given the global importance of mariculture, it is important that ICES continue to include mariculture as a primary focus in Action and Science plans

9 Update on joint Session (with WGMASC) for ASC 2008 on Ecological Carrying capacity in Shellfish Culture.

A theme session (to be chaired jointly by Francis O'Beirn (WGEIM) and Peter Cranford (WGMASC)) focusing upon the current state of assessing the ecological carrying capacity relating to shellfish culture in marine systems was deferred from ASC 2007 (Helsinki) to that of ASC 2008 (Halifax). The session has been designated as Theme Session H. Invitations were proffered to 27 potential authors and at the time of reporting 23 abstract submissions were received (16 talks and 7 posters). While there was general satisfaction at this number of submission, it was highlighted that the conveners should communicate with the Secretariat to ensure that sufficient time is allocated for each talk.

Action: WGEIM Chair to contact ICES Secretariat to determine the duration allocated for each talk at this session (Theme Session H) in the ASC 2008.

10 Discussion on existing and proposed new Terms of Reference

- 1) The group agreed to progress the work on **sustainability indices** by conducting intercessional work on developing practical indices for finfish aquaculture. This will be achieved by examining data from existing monitoring programmes as described in ToR A above. **Recommendation:** WGEIM to expand this ToR by providing case studies on the development of general sustainability indicators for finfish farming activities in member countries and report in 2009.
- 2) It was agreed to progress with the ToR 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.. **Recommendation:** WGEIM to continue with this ToR and report in 2009.
- 3) Evaluation of the outputs of a number of **integrated aquaculture** (multi-trophic culture systems) projects. In addition, the output of nutrients in IMTA or production systems in general, may lead to increased productivity or anoxic systems with consequences at both ends of the spectrum (water column and benthos). In bivalve culture, planktonic communities may be altered directly through grazing with respect to flushing and differential reproduction of plankton communities (e.g. compare copepod reproduction to heterotrophs). Various nutrient fluxes (from bivalves and structures as well as benthos) may impact water column nutrient dynamics and thus the whole pelagic ecosystem. This ToR will examine the fate of energy and nutrients from aquaculture systems and discuss the consequences for the environment and IMTA systems in general. **Recommendation:** WGEIM to expand this ToR to address the issue of energy and nutrient cycling associated with IMTA systems and report in 2009.
- 4) Further review the use of seed stock quality criteria in mariculture and their applications in term of ecological performance with the view to producing a full report in 2009 **Recommendation:** WGEIM to continue with this ToR and report in 2009.
- 5) Discussion took place on whether the issue of **sea lice and salmon farming** should be discussed by the group. In particular, the group expressed an interest in discussing was a unbiased review of the science underlying the management and arguments against salmon farming. It was pointed out that there were a number of recent symposia and publications which attempted to present current information on the subject consequently, there was not an obvious gap in how sea lice science is being disseminated. A potential gap identified was the absence of any overview or consensus summary of the current situation. What do we now know and where are the continuing uncertainties that need attention? It was appreciated that the subject was a very controversial one and any discussions and output would take considerable skills in presenting in an unbiased and acceptable format. It was not clear how the group should proceed with this. One solution, rather than the group take the subject on without mandate, would be for a member state to request that ICES advice on this subject. **Recommendation:** WGEIM to await an advice request from a member country to ICES on the subject of a review of the science underlying advice relating to sea lice and salmon farming.

- 6) Predicting the impact of **climate change** on marine systems has become an important and topical exercise for numerous authorities in recent years. Numerous predictions relating to sea level rise and water temperature changes have sparked considerable speculation on the potential to influence the distribution of marine species. Aquaculture species, particularly those found on the boundaries of climatic regions, may be at risk of greatest impact due to climate change. The geographical distribution of some highly productive and important aquaculture processes and species could expand as a consequence of a rise in sea temperatures (e.g. range expansion of reproducing populations of *Crassostrea gigas* to more northerly parts of Europe). An exercise was carried out by Matt Gubbins of the Fisheries Research Service, Aberdeen¹ (WGEIM 2007: Annex 5) in which he considered the consequences of projected changes in climate related environmental variables (rainfall, sea temperature) for aquaculture activities in Scotland. Considered specifically were the potential to increase the prevalence of disease-causing organisms (protozoan, bacterial, fungal and viral) and subsequent disease outbreaks as a consequence of stress induced by a rise in sea temperatures. Other issues covered were the potential to culture new species, influence on harmful algal blooms, the impact of increased run-off might have on shellfish waters classification and the impacts of increased storminess might have on mariculture activities. **Recommendation to MARC/ICES:** The committee considered assessing the potential impact of climate change on aquaculture activities a useful scenario setting exercise that might be replicated for all member states involved in marine aquaculture.
- 7) WGEIM and other ICES group have previously reviewed the issue on **fin fish feed usage** and constituents from member countries. However, the sustainability of utilising fish based feed products for marine fish farm activities continue to be questioned and justification continues to be sought. Feed producing companies are apparently endeavouring to find alternative sources. The goal of this work package is to provide an update within each member country of the proportion and constituents of alternative feeds used in finfish aquaculture. **Recommendation:** WGEIM to provide an update on fin fish feed usage and constituents from member countries to included in the meeting report in 2009.

¹ Gubbins, M (2006). Impacts of Climate Change on Aquaculture *in* Marine Climate Change Impacts Annual Report Card 2006 (Eds. Buckley, P.J, Dye, S.R. and Baxter, J.M), Online Summary Reports, MCCIP, Lowestoft, www.mccip.org.uk

11 Location of next meeting

An invitation was received by Dr. Francis O'Beirn, Marine Institute, Galway, Ireland to host the next meeting.

Action: The meeting of WGEIM in 2009 is to be held at the Marine Institute in Galway, Ireland from April 20-24, 2009.

12 Nomination of Chair

The tenure of the current Chair, Dr. Francis O'Beirn is complete. A new Chair was sought from the members of the group. Dr. Chris McKindsey was unanimously selected by the group to be nominated as Chair from 2009.

Recommendation: WGEIM recommend that Dr. Chris McKindsey be appointed Chair of WGEIM.

13 Any other business and close of meeting

Discussion took place on the overlap of the subject matters of ToRs between WGEIM and the Shellfish Culture Working Group (WGMASC), e.g. exotic species, shellfish culture impacts (sustainability indices). Alain Bodoy (founding Chair of WGMASC) highlighted that WGMASC was established as a consequence of little or no work being conducted on Shellfish aquaculture within ICES at the time. Attempts to stage a joint meeting between the two groups had not been successful. WGMASC 2008 identified that a recurring approach within WGMASC ToRs would be to review and cross-reference material produced within WGMASC with those conducted in other working groups, including WGEIM. It was recommended by WGEIM that in to foster better communication and compatible working relationships between that two group that at least one member attend both meetings in each year.

Dr. Edward Black announced that the FAO work on Risk Analysis developed partly in conjunction with WGEIM has been published by FOA under the GESAMP umbrella. The full report can be found at the FAO website *GESAMP Reports and Studies 76* at <http://www.fao.org/fishery/publications/en>

There was no other business to report. The meeting was closed on Friday April 19 at 12:00 by the Chair and special thanks was given to the host Dr. Stephen Cross and the University of Victoria for hosting the meeting in such a fine fashion.

14 Summary of Recommendations and Actions from WGEIM 2008

	Recommendations	Action
1	Recommendation: WGEIM to expand the Term of Reference on Sustainability Indices by presenting a worked example on the development of general sustainability indicators for finfish farming activities in member countries with a view to reporting at WGEIM in 2009.	WGEIM/MARC
2	Recommendation: WGEIM recommends that the 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..	WGEIM/MARC
3	Recommendation: WGEIM to continue with the ToR 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.	WGEIM/MARC
4	Recommendation: WGEIM further review the use of seed stock quality criteria in mariculture and their applications in term of ecological performance with the view to producing a full report in 2009.	WGEIM/MARC
5	Recommendation: The working group considered assessing the potential impact of climate change on aquaculture activities a useful scenario setting exercise that might be conducted in all member states involved in marine aquaculture.	MARC/ICES
6	Recommendation: WGEIM to provided an update on fin fish feed usage and constituents from member countries to included in the meeting report in 2009.	MARC/ICES
7	Recommendation: WGEIM to await an advice request from a member country to ICES on the subject of a review of the science underlying advice relating to sea lice and salmon farming.	MARC/ICES
8	Recommendation: WGEIM recommends that given the global importance of mariculture, it is important that ICES continue to include mariculture as a primary focus in Action and Science plans.	MARC/ICES
9	Recommendation: WGEIM recommend that Dr. Chris McKindsey be appointed Chair of WGEIM.	MARC/ICES
Recommendations Carried over from 2007		
10	Recommendation: WGEIM recommends to the Mariculture Committee and ICES, that a meeting is facilitated and organised with the participation of key representatives from ICES groups dealing with AES, (i.e. WGEIM, WGMASC, WGITMO and SGBOSV). This meeting (group) would be tasked to prepare a joint document highlighting, among other things, an update on the extent of introductions related specifically to aquaculture activities, the mechanism and interactions of the exotics with their new environment and; on the basis of these, identify information gaps and recommend specific research goals to fill these gaps.. It is clear that ICES could play a key role in addressing the growing need for information and advice on the management of AES. Presently, AES is mainly being addressed on national basis with significant inconsistencies in data collection, monitoring and management approaches. ICES could address some of these challenges and offers an international forum to provide coherent	MARC/ICES

	advice for the North Atlantic Zone. Further to this, WGEIM recommends to ICES, that a business case is prepared to organize a symposium to initiate the discussion among member countries on working collaborately to address identified research gaps, collection and sharing of data and provide advice on the mitigation and management of AES and their impacts on the marine ecosystem.	
11	Recommendation: WGEIM recommends a review of the state of the art (for both fish and shellfish) of off-shore aquaculture systems be carried out. That a Risk Analysis on the potential environmental interactions be carried out. That all analysis be carried with a strong industry and regulatory input (in order to identify technological, economical and regulatory challenges).	ICES/MARC
12	Recommendation: WGEIM recommends that it broaden its range of expertise to invite both industry and non-governmental organisation representatives, to deal with subject matters specific to their areas of interest and expertise. This will provide balanced and comprehensive advice to client organisations as well as member states. For example, industry representative could inform the development of integrated pest management strategies while NGOs could help to compare indicators for aquaculture and conservation. .	ICES/MARC
ACTIONS		
1	Action: WGEIM agreed that the documents relating to risk analysis of non-salmonid species be completed and submitted to an appropriate journal (Aquaculture) intercessionally.	WGEIM
2	Action: Member of WGEIM attend WGMASC meeting in 2009 and vice-versa to ensure compatibility of ToRs and to ensure no redundancy of effort.	WGEIM

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Annex 2: Agenda

Working Group on Environmental Interactions of Mariculture (WGEIM)

14-18 April, 2008

Victoria & Campbell River, British Columbia

Monday, 14 April

Joint Meeting between ICES-WGEIM and PICES

Chateau Victoria, Victoria, BC

- 09:00 Housekeeping and support arrangements – Steve Cross, Skip McKinnell
- 09:15 Introduction of Participants - All
Review of Workshop topics – Chair
- 09:30 Overview of Risk Assessment Work of WGEIM and FAO-GESAMP WG31–
Edward Black
- 10:00 Plenary Discussion and/or other presentations
- 11:00 *Comfort Break*
- 11:30 Wrap-up plenary and highlight main points for report.
- 12:00 *Lunch*
- 13:30 Resume
- 13:30 Fouling hazards associated with the physical structures used in mariculture
with a view to developing integrated pest management strategies – Chris
McKindsey
- 14:00 Plenary Discussion and/or other presentations
- 15:00 *Comfort Break*
- 15:30 Seed stock quality criteria in mariculture and their applications in term of eco-
logical performance – Thomas Landry
Seed Stock quality and Risk – Michael Rust
- 16:00 Plenary Discussion
- 17:00 Wrap-up Discussion and overview
- 17:30 End

Tuesday, 15 April

Joint Meeting between ICES-WGEIM and PICES

Chateau Victoria, Victoria, BC

- 08:30 An overview examples of sustainability indices proposed for mariculture ac-
tivities:
Risk and Sustainability – Edward Black
ECASA – Alain Bodoy
Sustainability Indicators for Aquaculture – Katsuyuki Abo
Sectoral Sustainability Indicators – Kats Haya
- 10:00 *Comfort Break*

- 10:30 Resume Presentations
 11:00 Plenary Discussion
 12:00 *Lunch*
 13:30 **Evaluation of the outputs of a number of integrated aquaculture(multi-trophic culture systems) projects including an commentary on the environmental and regulatory effects –
 West Coast, Canada - *Steve Cross*
 East Coast, Canada - *Shawn Robinson***
 15:00 *Comfort Break*
 15:30 Plenary discussion
 17:00 End Workshop

Wednesday, 16 April

- 06:30 (approx) Field trip to Aquaculture Facilities on Vancouver Island, Campbell River (details to be provided on Day 1) - WGEIM

Thursday, 17 April

WGEIM Meeting – Painters Lodge, Campbell River, BC

- 08:30 Housekeeping, Overview of work to be carried out and Assign Drafting groups for Meeting Report - All
 09:00 Presentation: Cultivation of Seaweeds in IMTA Systems – Opportunities and Limitation for the Cultivation of Porphyra and other Economically Important Species in Southern New England – Charles Yarish
 10:30 *Comfort Break*
 11:00 Drafting groups convene
 12:00 *Lunch*
 13:30 Drafting groups reconvene
 15:00 *Comfort Break*
 15:30 Drafting groups reconvene
 17:00 Plenary – Progress update
 17:30 End

Friday, 18 April

WGEIM Meeting continued.

- 08:30
- Update on joint Session (with WGMA SC) for ASC 2008 on Ecological Carrying capacity
 - Discussion re: WGEIM submission on consultation for Draft ICES Science Plan
 - Review Draft Summary Record and adoption of the scientific text of the report
 - Discussion on Recommendations
 - Discussion on new Terms of Reference
 - Location of next meeting
 - Any other business
- 12:00 End of 2008 meeting

LUNCH

Annex 3: WGEIM 2008 Terms of Reference

2007/2/MCC03 The Working Group on Environmental Interactions of Mariculture [WGEIM] (Chair F. O'Beirn, Ireland) will meet at the University of Victoria, British Columbia, Canada, from 14–18 April 2008 to:

- a) further evaluate the examples of sustainability indices proposed for mariculture activities and critically evaluate those SI's recommended by WGEIM and other for a;
- b) further investigate fouling hazards associated with the physical structures used in mariculture with a view to developing integrated pest management strategies;
- c) evaluation of the outputs of a number of integrated aquaculture (multi-trophic culture systems) projects including an commentary on the environmental and regulatory effects;
- d) review the use of seed stock quality criteria in mariculture and their applications in term of ecological performance;
- e) conduct a joint session with PICES and/or WGMASC whereby subjects of mutual interest will be discussed.

WGEIM will report by 20 May 2008 for the attention of the Mariculture Committee and ACOM.

Supporting Information

Priority	The activities of this group are fundamental to the work of the Mariculture Committee. The work is essential to the development and understanding of the effects of man-induced variability and change in relation to the health of the ecosystem. The work of this ICES WG is deemed high priority.
Scientific justification and relation to action plan	<p>ToR a) Sustainability indexes have, among other uses, been offered as a methodology to integrate large amounts of scientific information to underpin management and regulatory decisions. Some current research in the EU are evaluating an extensive range of environmental indicators and assessing their utility relating to aquaculture systems. However, sustainability implies that we have a notion of projection of impacts of activities and while this information can ultimately be garnered from monitoring or modelling activities for specific areas there are broader implications relating to the sustainability of activities that these methods cannot consider. However, in order to assess overall sustainability a broader approach to the sustainability issue should be considered to include specific targets such as 1) sustainable development of aquaculture (government perspective), 2) sustainable management of aquaculture areas (regional management), 3) sustainable operation of fish farms (operator's perspective) and, 4) Certification of sustainable aquaculture products (market view). The ultimate goal will be to define specifically what is sustainable in the context of aquaculture and advise on the specific criteria for SI to inform sustainable management of mariculture operations. Lead: Barry Costa-Pierce, USA.</p> <p>ToR b) Structure associated with mariculture activities can provide considerable surface area for colonisation of species not typically found in the culture area. This is presumably due to the increased habitat complexity and appropriate substrate for epifaunal organisms. In addition to the potential to provide a pathway for the introduction of an exotic nuisance species to a system, additional problems encountered are those associated with the management of the uisance to reduce the impact on the culture activity. This ToR will highlight existing examples and will address the management implications and potential mitigation strategies. Lead: Chris McKindsey, Canada.</p> <p>ToR c) Integrated aquaculture systems (encompassing a wide variety of types of multi-species systems) have been proposed as a direct way to utilise the wastes to create additional products of significant commercial/-environmental value. Nutrients from fish farms could support algal production; solid wastes from fish farms support bivalve production, etc. Some practical developments are starting to</p>

occur, and the EU has supported work in this area. However, the benefits do need to be fully elucidated and whether they are more applicable to open or closed systems. In addition, the co-culture of species may provide some regulatory conflicts that need to be clearly identified and addressed. Lead: Stephen Cross, Canada.

ToR d) For economical reasons, mariculture development is based on the continuous improvement of seed and fry, being wild or produced in hatcheries. How these improvements, particularly those which contribute to increase the physiological fitness and food efficiency may impact the use of the resources from the natural environment is a question of high relevance for decision making. The trade off between the economical and the ecological performance of mariculture, and consequently the regulations (e.g. licensing) to follow, is consistent with the objectives of sustainability and responsible natural resources management. The aim of this work will be to review the use of seed stock quality criteria in mariculture and their applications in term of ecological performance. Lead: Thomas Landry, Canada.

ToR e). Lead: Francis O'Beirn, Ireland

Resource Requirements	None
Participants	The Group is normally attended by some 12–15 members and guests
Secretariat Facilities	None
Financial	No financial implications
Linkages to Advisory Committees	ACOM
Linkages to other committees or groups	WGEIM interacts with WGMASC, WGAGFM, MARC
Linkages to other organisations	The work of this group is undertaken in close collaboration with the DFO Gesamp group, BEQUALM, OIE, EU, EAS, PICES

Annex 4: Cultivation of Seaweeds in IMTA Systems – Opportunities and Limitation for the Cultivation of *Porphyra* and other Economically Important Species in Southern New England

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The value of cultivated, managed and wild harvested seaweeds is valued at \$U.S. 6.2 billion with 92% of this value derived from aquaculture. The most valued of the maricultured seaweeds is the red alga *Porphyra*, or “nori” or “laver.” It is a major source of food for humans throughout the world, although it is primarily cultivated in Asia (China, Japan and South Korea). Worldwide production of this species has an annual value of over \$U.S. 1.34 billion. With renewed interest in using seaweeds and shellfish as biological nutrient removal systems (extractive aquaculture), there are other new opportunities for the aquaculture of species in this genus. In the past decade we have embarked upon a domestication process of using species of *Porphyra* indigenous to the northwestern Atlantic for cultivation in coastal and land-based recirculating systems. Whether or not *Porphyra* aquaculture will ultimately succeed in the Americas and in Europe will depend in large part upon several key factors, including: (1) successful transfer and modification of Chinese, Korean and Japanese cultivation technologies to local coastal environments; (2) resolving taxonomic complexities in the regional flora; (3) development of genetically improved strains (cultivars) of a marketable product; (4) establishing a constant supply of a “seedstock” of juvenile organisms that will be readily available; (5) the expansion of the areas presently considered for seaweed cultivation and (6) the potential of using this species and other seaweed species in an integrated multi-trophic aquaculture (IMTA) system. From a global perspective, the nutrient removal capacity of extractive crops like seaweeds and bivalves should strive to equal the discharge from the production of marine fish and shrimp (fed aquaculture). The development of IMTA practices is increasingly necessary to remedy the socio-economic and environmental limitations of fed aquaculture. We will address the implications of IMTA incorporating *Porphyra* in global seafood production as a way to reduce wastes and provide income to the marine farmer of the 21st century.

Annex 5: Impacts of Climate Change on Aquaculture in Marine Climate Change Impacts by Gubbins, M. (2006).

Annual Report Card 2006 (Eds. Buckley, P.J, Dye, S.R. and Baxter, J.M), Online Summary Reports, MCCIP, Lowestoft.

The dominant species currently produced by marine aquaculture (mariculture) in Scotland are Atlantic salmon, mussels and oysters. To date, there has been little published research or consensus opinion on the effects of climate change on Scottish mariculture. However, much can be inferred from the published literature on the effects of environmental variables on cultured species.

Given the current predictions¹, climate change is unlikely to have a significant effect on Scottish mariculture over the next decade. However, within the next 50 years or more, the forecasted changes are likely to result in noticeable effects. Rising average water temperatures will result in faster growth rates for some species (e.g. Atlantic salmon, mussels and oysters) but prolonged periods of warmer summer temperatures may cause thermal stress, particularly for cold water species (e.g. cod and Atlantic halibut) and intertidal shellfish (oysters), possibly preventing their culture at some sites, causing welfare problems and necessitating temperature control for broodstock of some species². However, warmer waters may provide opportunities to culture new species, or species that are currently economically marginal in Scotland³.

Diseases of cultured fish and shellfish⁴, including bacterial⁵, viral⁶, parasitic⁷ and fungal⁸ diseases, will be affected by a changing thermal regime, but in a largely unpredictable manner, due to the uncertainties in the temperature induced variations in the immune response of the cultured species. However, under conditions of thermal stress, cultured species are likely to be more susceptible to disease. Warmer conditions may also allow the establishment of exotic diseases, whereas diseases that occur under cool conditions, e.g. cold water vibriosis, may become much rarer. Sea lice are likely to remain a problem in salmon culture and rising temperatures will extend their season and may increase infective pressure, requiring more clinical interventions⁷. Increased storminess (higher frequency of strong wind speeds)⁹ predicted for certain seasons in some regions will increase the risk of escapes through equipment failure and may require relocation of some sites or changes in equipment design.

The forecasted warmer waters with calmer, drier summer months will have an effect on planktonic communities, although this will be difficult to predict in detail. There may be an increase in the frequency of harmful algal¹⁰ and jellyfish blooms, potentially causing more fish kills and closures of shellfish harvesting areas but the forecast reduction in summer precipitation may benefit classification of shellfish growing areas¹¹. Increased temperatures and more abundant plankton could also enhance early spawning success and spat fall of cultured shellfish species, to the benefit of the shellfish industry.

Explanatory notes

¹ Ocean climate change in mariculture areas

Scottish aquaculture in the marine environment (mariculture) is concentrated in the West coast of mainland Scotland and the Western and Northern Isles. Predictions of climate variables in these areas taken from the UKCIP published forecasts on www.ukcip.org/scenarios/ukcip02/scenarios/maps, were used to derive the subsequent predictions of effects on aquaculture. The following points relating to the pre-

dicted climate change in the key Scottish mariculture areas were used as the basis for predicting effects on mariculture:

All areas are predicted to experience rises in annual and seasonal mean water temperature up to 0.5 °C by 2020 and up to 2.5 °C by 2080. Over the same timescales, the summer precipitation is predicted to decrease (0-10% by 2020 and 10-30% by 2080) and winter temperature are predicted to increase (10-15% by 2080).

² Direct effects of temperature increase. Moderate confidence

An increase of 2°C may well adversely affect some species currently being farmed in Scotland as the thermal optima for the animals physiology may be exceeded for long periods of time during the summer months. Aquaculture of species such as Atlantic cod and Atlantic halibut may not be possible in the south of the country or be limited to area of deep water up-welling where the water is cooler than normal. Salmonid species are more tolerant of higher temperatures [1-6] than Atlantic cod [7, 8, 60] and Atlantic halibut [9-12] but higher peak temperature in the summer months, which may well be of longer duration than present could cause issues with thermal stress and potentially make some sheltered, warmer sites unsuitable for those species during the summer months

Optimal temperatures for on-growing large cod are generally low (approximately 7°C) [60] and although rising temperatures in Scottish waters may have some benefit to the growth rates of juveniles, growth rates of adults are likely to suffer.

Predicted increased growth rates of shellfish species (mussels and oysters) are dependant on the continued availability of the planktonic food supply. Intertidal shellfish, notably Pacific oyster (*Crassostrea gigas*) are currently susceptible to occasional mortality events during prolonged periods of hot weather. These would be likely to increase in frequency under warmer conditions. This species of oyster is not endemic to the UK and our current thermal regime is not optimal for spawning and natural recruitment from cultured stocks to establish wild populations. Under conditions of increased temperature, this may change.

Broodstock of some species (e.g. Atlantic halibut, Arctic charr) require low winter temperatures (3 months <6°C) for egg maturation. Production of high quality ova could require increased energy costs and capital expenditure associated with temperature control of broodstock and the availability of suitable broodstock sites may be restricted in the future.

³ Opportunies for new species. Low confidence.

Warmer water conditions could, potentially, allow new species to be cultured in Scotland where the current temperature maximums and minimums are marginal for the species, such as sea bass, sea bream, turbot, hake, scrombiforms (e.g. blue fin tuna), nori, ormer and Manilla clams.

⁴ Diseases of fish and shellfish. Low confidence.

From a disease point of view an increase in temperature can have many affects. Bacterial, viral and fungal disease will, in general, have shorter generation times. It is possible that some diseases, which transmit above a minimum temperature, will increase in prevalence. Not all effects on disease will be detrimental. For example the seasonal window of infectivity of some serious infectious conditions such as viral haemorrhagic septicaemia virus (VHSV) or Infectious pancreatic necrosis virus (IPNV) could be shortened, whilst others that require a minimum temperature to

cause clinical symptoms and transmission, such as Bacterial Kidney disease (BKD), could be lengthened. However, as most fish are poikilothermic their physiology is largely governed by the temperature of their surrounding environment and warmer water will mean the immune system of these animals will function more effectively in preventing the establishment of infections (up to the thermal optimum of the animal). It is therefore possible that clinical infections will not increase as fewer infections become established in the host. Once the thermal optimum is exceeded, then the function of the immune system will decline and physiological stress and oxygen depletion (warmer water holds less oxygen in solution than cold water) may well lead to disease and welfare issues.

Some viral infections can only occur between narrow temperature ranges, often 10-12°C usually during spring and autumn. Under warmer conditions this temperature window may decrease in the spring (and occur earlier in the year) as more rapid warming of water occurs in spring. Conversely if cooling of the environment is delayed during the autumn this temperature window may become extended and occur later in the year. Additionally warmer water conditions may allow the establishment of exotic diseases which are currently excluded as the climate is too cool to permit transmission. Beneficially, diseases that occur under cool environments, e.g. cold water vibriosis may become much rarer if the ecosystem is not cold enough for their biology.

If shellfish experience super-optimal thermal conditions (as will be more likely, particularly for inter-tidally cultivated species, given the predicted changes in temperature for the regions where they are cultivated) they will also be more susceptible to bacterial, viral and parasitic infections.

By their nature it is difficult to understand the response of diseases of unknown aetiology to increase in temperature. Some may become established in the UK, new ones may develop as a result of the warmer conditions while others that occur under cooler water regimes may decline.

⁵ Bacterial infections

As a rule of thumb as temperature increases the generation time of bacteria decreases [13] so under higher temperature regimes most bacterial infections would be predicted to progress faster once the host was infected, however, as mentioned above, assuming the animal is not at its thermal limit the fishes immune system will be operating more effectively and may well overcome the infection [14-17].

Under a rising temperature regime some bacterial disease of fish such as *Moritella viscosa* [18, 19] and cold water vibriosis [20-22] may decline in abundance as these diseases are characteristically seen in winter under cold water conditions and the new warmer environment may well adversely affect these bacteria. *Aeromonas salmonicida* and BKD, however, tend to occur under rising temperature regimes and during the summer months [20, 23-32]. If the environment warms by 2°C then it is possible that diseases such as these will occur earlier in the year (as the spring will be warmer and earlier) and the period these diseases are common may well be extended, increasing the infectious pressure of these pathogens in the environment. Warmer conditions may also favour currently rare bacterial infections such as *Clostridia*, allowing this pathogen to extend its range further north.

6 Viral diseases

Viruses effectively hijack the host's cells to replicate and the rate of replication is governed by the animal's physiology [13]. As most fish are poikilothermic [33] their physiology is largely governed by the temperature of their surrounding environment and warmer water will mean the animals will have a faster metabolism, which in turn will lead to increased viral replication within the host. It is worth pointing out again that, assuming the animal is not at its thermal limit, the fishes' immune system will be operating more effectively and may well overcome the infection as described above.

Some viruses can only infect their host during a very narrow temperature window (usually 10-12°C for most viruses currently of interest in Scotland [34-43]) an increased temperature regime may shorten this window as spring warming of water may well be increased reducing the period when infection can take place. Conversely cooling of the aquatic environment in autumn may be slower and the autumn infectious window may well increase in duration. This may result in a change in the seasonal distribution of diseases and it may well allow the pathogens to encounter new hosts as their duration in the aquatic environment is different from today. For example an increased infectious window in the autumn may mean that autumn migrating fish such as the critically endangered smelt may encounter pathogens that it does not normally meet.

7 Parasitic diseases

As parasites of fish and shellfish often have very complex life cycles involving many intermediate hosts, understanding how climate change would affect parasite abundance and the incidence of infection is more difficult to predict. Some parasites will become rare or disappear from Scottish waters because their physiology is not suitable to the warmer environment or their intermediate and final hosts decline in numbers as the environment changes, [44-46] migrate further north to cooler waters [44-46] or the parasites thermal limits are exceeded [47, 48]. However other parasites will become more abundant as their definitive host and intermediate hosts colonise the new environment or, as Scottish waters warm up, the environment will be able to support new parasitic organisms, which are currently at or below their thermal minimum, and they would be able to survive and colonise new hosts in the warmer ecosystem. For example *Caligus curtis*, currently rare in Scottish waters, may effectively extend their range further north, especially if susceptible fish hosts can overwinter or establish viable populations.

Parasites with direct life cycles, such as sea lice (*Lepeophtheirus salmonis*) are a little easier to predict potential changes in their biology. It would be expected that a 2°C increase in water temperature will decrease the life cycle by approximately 2 days and permit more generations in a season [47-49], potentially increasing the infective pressure of this parasite in Scotland. However, the time the copepodid stage remains infectious will also decrease from about 10 days under current climatic conditions to around 8 days under the warmer regime suggested here [50, 51]. During the overwintering period more copepodid and mobile stages may survive allowing a more rapid establishment of infection each spring. Currently *L. salmonis* has a population boom in early May and declines in numbers in late October [52]. Under a warmer regime with warmer springtime temperatures the spring lice bloom may occur earlier in the year and the autumn decline pushed into November or even December. Such an extended season would undoubtedly lead to more clinical interventions to control lice as well as increased lice infective pressure within the environment.

⁸ Fungal disease

Like bacteria, as temperature increases the generation time of fungal organisms decreases so that, under higher temperature regimes, most fungal infections would be predicted to progress faster once the host was infected. However, as mentioned above, assuming the animal is not at its thermal limit, the fishes' immune system will be operating more effectively and may well overcome the infection.

Saprolegnia is one disease that could cause concern in a warming environment. Currently this disease occurs each spring and causes major welfare issues with parr and smolts often necessitating clinical intervention and treatment with antifungal drugs. Under warmer conditions it is feasible that *Saprolegnia* would occur earlier in the year and progress faster in infected fish [53-59] and the autumn decline in the disease would occur later in the year.

Fungal diseases exotic to Scotland could become established is a potential concern especially as the trade in tropical ornamental fish (including goldfish, which are often cultured under warm water regimes in the Middle & Far East, China and USA) may be a source of introduction of exotic fish fungi into the country.

⁹ Storminess. Very low confidence.

The UKCIP results for wind speeds are very uncertain, such that it is not possible to assign a low confidence value to changes in wind speed. It is predicted that winter depressions will become more frequent, with deeper lows. However it is difficult to clearly predict regional effects. Based on the existing UKCIP forecasts, some areas are predicted to experience an increase (up to 10 percent) in the 20 year return period daily mean speeds in some seasons (e.g. West coast of Scotland in autumn/winter and Orkney/Shetland in summer). This represents an increase in the frequency of stormy conditions, which will have significance for the integrity of aquaculture structures and increase the risk of escapes. Mean daily wind speeds with 2 year return periods are predicted to decline over much of the West coast of Scotland during summer months. These calmer conditions are likely to have effects on planktonic communities (see below).

¹⁰ Harmful algal blooms. Low confidence.

Climate change is having a complex effect on phytoplankton communities. Several studies have associated rising surface temperatures with an increase in the relative abundance of flagellates and dinoflagellates (compared to diatoms), e.g. in the NE Atlantic [61], North Sea [62], Baltic Sea [63] and Norwegian coast [64]. Both of these groups contain potentially toxic or nuisance species which can be responsible for stress or kills of cultured finfish or result in harvesting closures for shellfish growing waters. There are many complicating factors and for the regions where Scottish aquaculture is concentrated, there are no accurate predictions for the future trends in the occurrence of such harmful algal blooms (HABs). Changes in precipitation will affect the salinity of coastal waters as well as the stratification of water columns and the availability of nutrients for phytoplankton growth. In addition the zooplankton communities which graze on phytoplankton communities have also been observed to be changing.

It is possible that the future hydrodynamic regime will favour a different planktonic community to present. It is possible that species currently absent or rare in Scottish waters may become established and new toxic / nuisance species may pose problems for aquaculturists. The phenology (temporal patterns of occurrence) of planktonic

species are also likely to be altered [62], with effects on the timing and efficacy of shellfish spat fall.

¹Shellfish Classification. Low confidence.

Precipitation, by influencing run-off from land, has an impact on shellfish classification (determined according to the presence of enteric bacteria in cultured shellfish). Increased run-off from land where livestock faecal material is present can increase the presence of enteric bacteria in shellfish. Shellfish farmers may be prevented from selling or be required to depurate shellfish harvested from areas with a poor Classification. Under a regime of reduced precipitation during summer months it is reasonable to expect that this situation will become less frequent.

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Annex 6: WGEIM Terms of Reference for 2009

The **Working Group on Environmental Interactions of Mariculture** [WGEIM] (Chair: Chris McKindsey*, Canada) will meet at the Marine Institute, Galway, Ireland from 14–18 April 2009.

- a) further evaluate the examples of sustainability indices proposed for mariculture activities and critically evaluate those SI's recommended by WGEIM and other fora;
- b) further investigate fouling hazards associated with the physical structures used in mariculture with a view to developing integrated pest management strategies;
- c) review the outputs of a number of integrated aquaculture (multi-trophic culture systems) projects and address the issue of energy and nutrient cycling associated with IMTA systems and report in 2009;
- d) review the use of seed stock quality criteria in mariculture and their applications in term of ecological performance;
- e) assess the potential impact of climate change on aquaculture activities relevant to each ICES member state;
- f) provide an update on fin fish feed usage and constituents from member countries to included in the meeting report in 2009.

WGEIM will report by XX May 2009 for the attention of the Mariculture Committee and ACOM.

Supporting Information

Priority	The activities of this group are fundamental to the work of the Mariculture Committee. The work is essential to the development and understanding of the effects of man-induced variability and change in relation to the health of the ecosystem. The work of this ICES WG is deemed high priority.
Scientific justification and relation to action plan	<p>ToR a) The group agreed to progress the work on sustainability indices by conducting intercessional work on developing practical indices for finfish aquaculture. This will be achieved by examining data from existing monitoring programmes in member countries. Lead: Ian Davies, Scotland.</p> <p>ToR b) Structure associated with mariculture activities can provide considerable surface area for colonisation of species not typically found in the culture area. This is presumably due to the increased habitat complexity and appropriate substrate for epifaunal organisms. In addition to the potential to provide a pathway for the introduction of an exotic nuisance species to a system, additional problems encountered are those associated with the management of the uisance to reduce the impact on the culture activity. This ToR will highlight existing examples and will address the management implications and potential mitigation strategies by examinaning a range of case studies from Canada and Spain specifcially. Lead: Chris McKindsey, Canada.</p> <p>ToR c) Evaluation of the outputs of a number of integrated aquaculture (multi-trophic culture systems) projects has been covered by WGEIM for the last number of years and will continue to be evaluated by the group. In addition, the output of nutrients in IMTA or production systems in general, may lead to increased productivity or anoxic systems with consequences at both ends of the spectrum (water column and benthos). In bivalve culture, planktonic communities may be altered directly through grazing with respect to flushing and differential reproduction of plankton communities (e.g.</p>

compare copepod reproduction to heterotrophs). Various nutrient fluxes (from bivalves and structures as well as benthos) may impact water column nutrient dynamics and thus the whole pelagic ecosystem. This ToR will examine the fate of energy and nutrients from aquaculture systems and discuss the consequences for the environment and IMTA systems in general. **Lead: Stephen Cross and Shawn Robinson, Canada.**

ToR d) For economical reasons, mariculture development is based on the continuous improvement of seed and fry, being wild or produced in hatcheries. How these improvements, particularly those which contribute to increase the physiological fitness and food efficiency may impact the use of the resources from the natural environment is a question of high relevance for decision making. The trade off between the economical and the ecological performance of mariculture, and consequently the regulations (e.g. licensing) to follow, is consistent with the objectives of sustainability and responsible natural resources management. The aim of this work will be to review the use of seed stock quality criteria in mariculture and their applications in term of ecological performance.

Lead: Thomas Landry, Canada.

Tor e) Predicting the impact of climate change on marine systems has become an important and topical exercise for numerous authorities in recent years. Numerous predictions relating to sea level rise and water temperature changes have sparked considerable speculation on the potential to influence the distribution of marine species.

Aquaculture species, particularly those found on the boundaries of climatic regions, may be at risk of greatest impact due to climate change. The geographical distribution of some highly productive and important aquaculture processes and species could expand as a consequence of a rise in sea temperatures (e.g. range expansion of reproducing populations of *Crassostrea gigas* to more northerly parts of Europe). Other issues that might be covered are the influence changing climate might have on the prevalence of disease causing organisms, the potential to culture new species, influence on harmful algal blooms, the impact of increased run-off might have on shellfish waters classification and the impacts of increased storminess might have on mariculture activities. **Lead: no lead assigned yet.**

Tor f) WGEIM and other ICES group have previously reviewed the issue on fin fish feed usage and constituents from member countries. However, the sustainability of utilising fish based feed products for marine fish farm activities continue to be questioned and justification continues to be sought. Feed producing companies are apparently endeavouring to find alternative sources. The goal of this work package is to provide an update within each member country of the proportion and constituents of alternative feeds used in finfish aquaculture. **Lead: no lead assigned yet.**

Resource Requirements	None
Participants	The Group is normally attended by some 12–15 members and guests
Secretariat Facilities	None
Financial	No financial implications
Linkages to Advisory Committees	ACOM
Linkages to other committees or groups	WGEIM interacts with WGMASC, WGAGFM, MARC
Linkages to other	The work of this group is undertaken in close collaboration with the DFO

organisations

Gesamp group, BEQUALM, OIE, EU, EAS, PICES
