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

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Contents

Executive summary

WGEIM met at the IFM-GEOMAR, Kiel, Germany from 16–20 April. Eight members, from six countries, attended the meeting. Five terms of reference were addressed by the group and are summarised below.

ToR A: Members of the WG continued intercessional work on a joint ICES/FAO project, leading to a meeting of GESAMP Working Group 31 at FAO, Rome in November 2006. The outcome of that meeting, and subsequent work, is a draft report for GESAMP prepared through the collaborative efforts of the GESAMP Working Group 31 on Risk Assessment and Communication, and ICES-WGEIM. The title of the report is "Integrated Risk Assessment and Communication For Environmental Interactions of Aquaculture". In addition to the GESAMP report, WGEIM members have prepared extended drafts of risk analyses of the escapes of cultivated halibut, sea bass, sea bream and turbot (in addition to the cod document included in the FAO report). WGEIM agreed that efforts should now be made to complete these drafts with a view to submitting a package of reports to a journal for publication intercessionally.

ToR B: The group continued to review the applicability of sustainability indicators for aquaculture. Work on this ToR consisted of a review of progress made to date on the development of SI's proposed for mariculture activities. A number of shortcomings of many SIs identified and approaches to develop SI continue to be identified by the group. Broad definitions of SI include social and economic elements which are not covered in the deliberations of WGEIM, due to lack of relevant expertise. The question of scale was identified as critically important when considering sustainability. Future deliberations of the group will consider SIs from the aspect of scale ranging from farm-level to global indicators. The group considered the theoretical considerations identified in WGEIM 2006 and 2007, and attempted to adapt them into a practical assessment tool. The prominent themes (benthic enrichment, nutrient release, feed materials, energy consumption, disease considerations and occupancy of space) of environmental interactions of mariculture were identified with a view to proposing indicators or indices of effect. Information pertaining to these would be sought for each member state and presented at WGEIM 2008.

ToR C: WGEIM members will endeavour to finish a review manuscript of alternate feeds in mariculture and submit it for publication in a peer reviewed scientific journal.

ToR D: It is generally accepted that the structures associated with aquaculture activities have the potential to facilitate the spread of non-native and/or nuisance species. In order to introduce measures to control or eradicate these pests, detailed information on the reproductive biology, general ecology and population dynamics of the species in question is required. Additional information relating to threshold values and potential control measures are all important to the development of Integrated Pest Management (IPM) strategies to manage and control the effects of the nuisance species. WGEIM considered some of the responses and information requirements that have been proposed in dealing with Aquatic Invasive Species. The introduction of rapid response measures to the appearance of an exotic species is an integral part of any mitigation measure. The coordination of any response should be conducted with clear lines of communication and responsibility assigned to participants. Monitoring programs have been established in a number of countries with nascent programs being developed in others. Control measures can be based upon a number of different strategies relying on information on the biology or ecology of the nuisance species, potential biological control strategies including the exploitation of predator-prey interactions, the use of genetically modified organisms and genetic modification to reduce viability (e.g. use of triploids). Some biological control measures are considered to be un-acceptable by numerous

experts (e.g. use of exotic predators or viruses). WGEIM will examine these control measures in more detail during subsequent meetings.

ToR E: A review was conducted of the of the activities of WGEIM during the period 2003-2007. It is apparent that the group have been active both within the framework of ICES and externally with numerous collaborations among the members of the group. These collaborations manifest themselves as interactions on specific research projects, exchange of students and joint publications. All of the terms of reference covered by the group were also reviewed and their applicability to the ICES Strategic plan was also considered. Of the twelve subject areas covered by the group in the last five years, seven have been completed in a satisfactory fashion, three have been carried over as recurring ToRs for future meetings of the group, while two were transferred to the new group on Integrated Coastal Zone Management (WGICZM). A canvass was carried whereby emerging issues related to mariculture were identified. It was broadly agreed that thee issues should be addressed in the context of three broad themes either individually or in combination (i.e. Climate Change, Marine Spatial Planning and Sustainability of Activities). It is apparent from this review that ICES is well positioned to provide advice on emerging issues relating to mariculture and with additional expertise this ability will be enhanced. As a consequence two strong recommendations stem from the group, 1) given the global importance of mariculture, it is important that ICES continue to include mariculture as a primary focus in future action plans and, 2) that WGEIM broaden it range of expertise to invite both industry and non-governmental organisation representatives, to deal with subject matters specific to their areas of interest.

The nomination of a new chair was discussed. It was agreed that the existing Chair should be invited to act as co-chair with Dr. Chris McKindsey for the 2008 meeting, after which Dr. McKindsey would serve as chair alone

The next meeting was arranged for April 14-18 at the University of Victoria, British Columbia. The location was considered for two reasons, 1) to take up the kind invitation of Dr. Steve Cross from 2005 and, 2) to facilitate a joint meeting between WGEIM and PICES aquaculture group.

1 Opening of the meeting

Francis O'Beirn (Chair) opened the 2007 meeting of the Working Group on the Environmental Interactions of Mariculture (WGEIM) at the IFM-GEOMAR, Kiel, Germany from 16–20 April. This year's meeting was attended by 8 scientists from six countries (Annex 1).

The group was welcomed to the IFM-GEOMAR by Dr. Helmut Thetmeyer, who outlined some of the proposed events for the week. The Chair, on behalf of the group, expressed considerable gratitude to Dr Thetmeyer for his preparations and providing facilities for the meeting.

It was noted that during the intercessional period, a paper originally prepared as a term of reference during WGEIM 2006;

Bivalve aquaculture and exotic species: a review of ecological considerations and management issues - Christopher W. McKindsey, Thomas Landry, Francis X. O'Beirn, Ian M. Davies was submitted and accepted for publication in the Journal of Shellfish Research.

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. The ultimate goal of the week was to conclude a number of recurring terms of reference, 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.

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, who would be responsible for compiling the contributions of the others within the group. There were one deviation from the list of members of the subgroups assigned prior to the meeting and that was that the lead author, Barry Costa-Pierce, was not present at the meeting. However, it was agreed that the recommendations from this ToR provided in the WGEIM 2006 report would be the starting point upon which to address this ToR at this meeting.

3 ToR A - Risk assessment of escapes of non-salmonid fish species from cultivation

Ian Davies reported that, since WGEIM 2007, members of the WG undertook intercessional work on this joint ICES/FAO project, leading to a meeting of GESAMP Working Group 31 at FAO, Rome in November 2006. The outcome of that meeting, and subsequent work, is a draft report for GESAMP prepared through the collaborative efforts of the GESAMP Working Group 31 on Risk Assessment and Communication, and ICES-WGEIM.

The title of the report is "Integrated Risk Assessment and Communication For Environmental Interactions of Aquaculture", the draft executive summary is provided in Annex 4, and the draft abstract reads:

> To effectively support an open and transparent approach to sustainable resource use, risk assessment and communication must be able to fit within a broader social, economic and environmental decision making framework. The communication aspects become paramount in enabling sustainable development in that type of decision-making environment. In today's environmentally conscientious societies,

without social licence no activity is truly sustainable. Scientific knowledge has to be developed and presented in a clear manner that fully acknowledges the extent and limits of our ability to predict the consequence of development whether it is the development of a single farm site or development of a number of sites that may have a cumulative effect that can not be predicted on the basis of the activities of at a single site or even an entirely new industry.

This publication presents a set of objectives, goals methodologies and a checklist for risk assessment and communication that is designed to enhance risk communication. It is also structured to ensure that risk assessment is a scientific exercise in predicting environmental change. Instruction is given on how socio-economic values can be utilized with environmental risk assessment in open and transparent decision-making for questions of resource allocation. In addition the risk assessment methodologies are designed to present a clear picture of the role of uncertainty in prediction error. This approach to risk assessment also helps target mitigation and research efforts to ensure knowledge of the causes and effects of the aquaculture's environmental interactions.

A set of six case studies are also presented to illustrate the use of the risk assessment methodologies. These examples of environmental interactions span a range of cultured species from fish to molluscs and shrimp.

The contents of the report are:

Chapter 1 - Introduction

Chapter 2 – Environmental effects, risks and uncertainties associated with coastal aquaculture

Chapter 3 – Risk analysis

Chapter 4 – Risk analysis in practice for coastal aquaculture

Chapter 5 – Risk Communication

Chapter 6 – Case Studies

6.1 Fish farming effects on the benthic community changes due to sedimentation - Kenny Black and Chris Cromey.

6.2 Risk assessment of the potential decrease of carrying capacity by shellfish farming – Cedric Bacher

6.3 Risk analysis of the potential interbreeding of wild and escaped farmed cod (Gadus morhua Linnaeus) - I. M. Davies, C. Greathead and E. Black

6.4 Risk analysis of the decline of laminariales due to fish farming waste – R. Petrell, P. Harisson and E. Black

6.5 Risk analysis of the soil salinization due to low-salinity shrimp farming in central plain of Thailand – Seng-Keh Teng

6.6 Risk Analysis of Coastal Aquaculture: Potential Effects on Algal Blooms - K. Yin, P. Harisson and E. Black

WGEIM noted that the report would be presented to the annual meeting of GESAMP in May 2007, and hoped that the report would then quickly progress to a final version.

Over the past two years, WGEIM members have prepared extended drafts of risk analyses of the escapes of cultivated halibut, sea bass, sea bream and turbot (in addition to the cod document included in the FAO report).

Action

WGEIM agreed that efforts should now be made to complete these drafts during the meeting and over the subsequent period with a view to submitting a package of reports to a journal for publication. Ian Davies to lead on this task with support from other members of WGEIM as may be required.

4 ToR B - Further evaluate the examples of sustainability indices proposed for mariculture activities and critically evaluate those SIs recommended by WGEIM and other forums

4.1 Comments on the 2006 Report

The WG reviewed the material on sustainability indices from the WGEIM 2006 report (ToR c, section 7) and felt that some comments were in order:

- The 2006 report begins with the words, "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" (emphasis added). Although the WGEIM has in the past included some social scientists, there were none present at this meeting and this clearly poses a limitation on the ability of the group to completely address this issue. ICES may need to find an effective mechanism for inclusion of social scientists and other experts to address questions outside the sphere of its traditional scientific work.
- The statement that "Indicators must be measurable objects that can be simplified by aggregation and calculation. Outcomes from theoretical models cannot be considered as indicators." may be overly restrictive. Sustainability by any definition implies predicting that future conditions will be in some sense satisfactory, and the only way to predict future conditions is by the use of models. Although these models may be simple enough to qualify as "composite indicators", to use a concept which is discussed at length in section 7.3 of the 2006 report, it is difficult and often arbitrary to distinguish between model output and a composite indicator. For example, the rate at which a site releases nutrients into the water column is a possible indicator (N), and the residence time of the water body is another possible indicator (T), and the product P=NT would probably be accepted as a composite indicator. However the equilibrium solution of the uptake-clearance equation dC/dT=N-C/T, which is clearly a "theoretical model", turns out to be P. The fact that P is the outcome from a theoretical model should not invalidate its use as a composite indicator.
- There is extensive discussion in the 2006 report of the work of the ECASA project on indicators that can be used to assist in the development of sustainable aquaculture, but the two ECASA members in the group are not confident that these indicators will satisfy the definitions described in the 2006 report. Although the basic objective underlying ECASA is to make EU aquaculture sustainable, the approach is somewhat different. The focus of ECASA is more on identifying indicators for selecting suitable sites for aquaculture and monitoring conditions and trends than on the more ambitious goal of indicating sustainability of certain types of aquaculture activities in a larger region or even globally. ¬ ECASA is identifying indicators both of the impacts of aquaculture on the environment and of the effects of environmental conditions on aquaculture, and is making extensive use of modelling to identify sustainable strategies.

To address these issues we include an annex (Annex 5) dealing with indicators prepared by W. Silvert which is based on a 2001 report he did for the Canadian Department of Fisheries and Oceans. The full report, which deals with the use of fuzzy traffic lights in fisheries management, can be found at http://silvert.org/FTLM.pdf. Although this report deals with capture fisheries and does not address aquaculture, it does however address in considerable detail the traffic light methodology identified as important in the 2006 WGEIM report. The WG did not discuss the traffic light concept beyond the scope covered by this report.

4.2 Purposes of Indicators of Sustainability

A key question to be resolved in seeking to define Indicators of Sustainability is how they are to be used and what purposes they serve. One obvious function is to guide the development of regulations implemented by government agencies with responsibility for environmental protection and related areas. Another is to meet the needs of the industry which is increasingly under attack for practices which may appear to be unsustainable, and which might benefit from clear guidelines on operating sustainably.

The United Nations Division for Sustainable Development has been carrying out a program to develop Indicators of Sustainability and as one would expect from a very general global initiative, much of the emphasis is on the social and economic aspects of sustainability – areas where the WGEIM has limited experience. The focus is largely on resource use, capital investment, and social factors such as employment and development. Members of the WGEIM have addressed one major resource question, the use of wild fish to produce aquaculture feed (Annex 4 of the 2002 report), and continues to work on this important question (ToR C this report). The WGEIM has not however investigated other aspects of resource use, such as energy consumption and capital requirements, and these should probably be referred to specialists in those areas.

Although the industry may have concerns about the potential for regulatory control based on Indicators of Sustainability, there are also potential benefits. It has been noted that "it would be possible … to apply a comprehensive Sustainable-label (S-Label) to aquaculture products which have followed EAA [Ecosystem Approach to Aquaculture] guidelines" and there is already a trend in some sectors of the food business to purchase only sustainably produced products when possible.

Some of the questions raised about the sustainability of aquaculture are very general and affect the industry as a whole, such as concern about whether the culture of carnivorous species like salmon can ever be sustainable. Other issues are more specific and can be applied at the local level. This means that a variety of different types of Indicators will be necessary. The development of Indicators cannot proceed efficiently without planning for how these are to be implemented.

The question of scale is therefore clearly important when considering sustainability. The present trends in various national or international contexts tend to adapt the concept to every level of any human activity. Considering aquaculture development, the following levels can be recognised:

1) farm and farmer: addresses the "quality" of a single (existing or future) enterprise
2) production system: addresses a particular set of technical and resources uses
3) production sector: combines the various technical and resource uses options
4) coastal zone: considers other users/competitors of a given space; allows comparison of sets of aquaculture indicators from different origins
5) national and international: considers global trends and governance issues.

It is obvious that the nature of the indicators appropriate for the description of trends towards increased sustainability of aquaculture will be different in these different contexts. To date, the SIs that have been produced are mainly relevant to the latter levels (mainly to raise awareness among various stakeholders), while the adoption of SIs for the farmer or for an aquaculture system have not been intensively developed or adopted.

When addressing the farm level, there is a requirement for practicality and cost effectiveness of the collection of the data that will be used, directly or indirectly, for the indicators. The data produced at that level have to be relevant in two directions:

- characterizing the "sustainability index" of the farm towards its clients and monitoring bodies;
- adapted for aggregation to further levels.

Future recommendations should include those dimensions in order to be operational. For example, the data collected by farmers on behalf of their licensing authority should be utilized. Where possible, data should be utilisable in other contexts as well, for example WFD and later, the Marine Strategy Directive.

Aquaculture sustainability indicators need to be developed in order (1) to be of use when matching with indicators from other origins (be they other aquaculture systems or other sectors) and (2) to measure the progress being made over time. The purpose is to assist in the tasks of decision makers and planners in order to achieve the best possible compromise. For example, cage farming and closed (recirculating) system can be compared, but their relative ranking using sustainability criteria needs other tools (in which weighting methods have a major impact). As a consequence, SIs do not set targets or thresholds, but show relative values and allow comparisons to be made and trends to be identified. This also suggests that the literature to be reviewed by the WGEIM should extend beyond aquaculture, and is relevant to the way that ICES and consequently the WGEIM evolve in their principles and management.

4.3 An approach to the development of practical indices related to 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 therefore provide a pathway to indicators of performance. In the context of mariculture, it may be possible to express desired (but perhaps unachievable) conditions in terms of zero impact on marine ecosystems. Movement towards such conditions is therefore desirable movement towards increased sustainability of the environmental interactions of mariculture activities.

It has been recognised 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 control, disease interactions with wild stocks, and energy consumption. Most of these interactions have been discussed at previous meetings of WGEIM. Transfer of disease 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 had no adverse 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 no impact on the marine environment. In some cases, this was relatively straightforward, for example, 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 compiled Table 1, in which each of the primary forms of environmental interaction of marine fish cultivation are linked with an expression of minimised impacts on the marine environment, indicating the desirable direction of change leading to progressively improving levels of sustainability. The WG had national or regional scales, rather than more local (e.g. individual farm site) in mind when developing Table 1, although aspects of the table may be transferable to smaller scale assessments.

Suggestions are then made in Table 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 WG suggested that some of the proposed indices could be tested using data and modelling 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 WG made no suggestions regarding disease transfer from farmed to wild fish, as this is outside their current remit.

WGEIM concluded that the proposals in Table 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.

Action

Members of WGEIM agreed to gather information and data intersessionally to explore the usefulness and interpretability of the proposed indices, and to present this information at WGEIM 2008.

Table 1. Suggested desirable directions of change to improve sustainability and indices of change with respect to interactions of marine fish farming with the marine environment

Type of environmental interaction	Expression of minimised impacts on the marine environment, indicating the desirable direction of change	Measured by	Source of data	Feasibility
Benthic enrichment	No impact on benthos	Area degraded per tonne of production	Modelling of impacted areas by site against some agreed standard, for example ITI, AMBI, or sulphide etc. Compliance monitoring.	Could be done now
Nutrient release	No nutrients released to surrounding water	Mass of nutrient N/P released per tonne of production	Mass balance calculations by site or by industry sector	Could be done now
Genetic interaction	No interactions with wild con-specifics	EITHER: Number of escapees per year per tonne production or The absolute number of escapees per year	Reporting of escapes to a regional/national data centre	Probably only feasible now in some countries
Feed materials	Minimised OR no impact on marine resources	EITHER: Proportion of marine oil/protein used in feed or Mass of marine oil/protein used per tonne of production or Absolute mass of marine oil/protein used.	Information from feed manufacturers on feed composition and modelling of feed utilisation	Could be done now
Energy consumption	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

Type of environmental interaction	Expression of minimised impacts on the marine environment, indicating the desirable direction of change	Measured by	Source of data	Feasibility
Disease control	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 (if willing) Sampling of industry practice and experience. Returns to EPAs etc.	Probably only feasible now in some countries
Disease interactions	No transfer of disease to wild species	?	?	
Occupation of space	Minimised utilisation of space	Area of sea surface allocated per tonne of production	National data centres, and licensing authorities.	Could be done now

5 ToR C - Complete the review on alternative feeds with a view to generating a manuscript to be submitted for publication in a peer reviewed scientific journal

WGEIM 2006 initiated a study of evaluate the sustainability of utilizing fish meal and fish oil from the reduction fisheries in fish feed for mariculture. Pressures for the need to find alternative sources of lipid and protein for aquaculture feed are: increase in growth of fed aquaculture, increases in the cost of reduction fisheries products, develop more environmentally friendly, concerns on the long-term sustainability and ethics of using potentially food-grade fishery resources for animal feeding rather than for direct human consumption and decrease the concentration of persistent organic contaminants. However, there are also demands to use only ingredients that are in the natural fish diet. The objective for WGEIM 2008 is to complete the review as a manuscript for publication on the progress being made in identifying alternatives to fish meal and oil as protein and lipid sources for feed used in finfish aquaculture.

Total finfish and crustacean aquaculture production finfish and crustacean aquaculture production increased from 2.1 in 1976, 15.9 in 1995 to 34.0 million tonnes in 2005. Of this farmed salmon, marine-brackish water reared rainbow trout, sea bream and sea bass in 2005 was 1.99 million tonnes. Aquaculture production is predicted to increase along with the world population and demand for food and is expected to exceed total capture fisheries production by 2015. Growth in salmon and aquaculture production will likely increase the demand and price for fishmeal and fish oil that are ingredients of aquafeed.

The quantities of landed fish and shellfish from capture fisheries destined for reduction into meals and oils and other non-food purposes was 21,370 thousand tonnes in 2003 or 23.4% total capture fisheries landings and has remained fairly constant since 1986. The total estimated amount of fish oil and fish meal used within compound aquafeeds has grown from 234 to 802 thousand tonnes and from 963 to 2,936 thousand tonnes from 1994 to 2003, respectively. Between 50 and 75% of commercial salmon feeds are currently composed of fishmeal and fish oil and any price increases in these finite commodities will have a significant effect on feed price and farm profitability as salmon feeds and feeding representing between 60 to 70% of total farm production costs. For finfish aquaculture to be sustainable in the long-run it must reduce its dependence upon these finite commodities.

In the short term this is of most concern for fish oil, and could be partly resolved through the use of plant oils and animal fats as dietary energy sources supplemented with marine fish oils reserved only as dietary providers of essential fatty acids. Recent advances in feed formulation, feed manufacturing technology, and on-farm feed management have all resulted in increased fish growth, reduced fish production costs, and reduced feed conversion ratios (FCRs).

On of the primary effects of substituting plant oils for fish oils in fish diets is an unintentional alteration in the fatty acid composition of the diet, which in turn affects the fatty acid composition of the fish. Plant oils contain high levels of unsaturated fatty acids, and low levels of saturated fatty acids compared to fish oil and may have beneficial effects on the health of the fish. Alterations in the total saturated fats and polyunsaturated fatty acid levels can affect the flesh characteristics and consumer acceptance.

The possibility of using “finishing” diets containing fish oil to reverse the changes in fatty acid composition caused by feeding with plant oils has been examined. For fish previously fed plant oil diets, the time taken to achieve fatty acid composition recovery varies not only depending on what the original oil source was, but also for which fatty acid the composition recovery is being evaluated, and depending on fish species and size. In terms of fillet quality, fillets of gilthead seabream and seabass fed plant oils as partial replacement of fish oils were well accepted by trained judges when assessed cooked. However, decreases in desirable fatty acids may reduce the health benefits to human consumers.

Atlantic salmon and juvenile red seabream fed diets in which 100% of the fish oil was replaced with various vegetable oils were without significant effect on growth. However, when a single plant oil is used over a long period of feeding, detrimental effects may occur in terms of immunosuppression or stress resistance. These effects are mitigated by the inclusion of a blend of plant oils instead of a single plant oil in the diet. Various reversible effects of plant oils in diet have been observed in lipid metabolism, storage and mobilization, and respiratory and cardiovascular effects in fish. While fatty acid profiles of both egg and fry of salmon were changed but no changes were observed in egg weight, number or proximate composition.

The levels of dioxins and dioxin-like PCBs in plant oils are considerably lower than in fish oils. Therefore, substitution of plant oils in place of fish oils as the primary lipid ingredient in feeds for aquaculture fish has been explored with promising results.

Fish meals are commonly utilized as protein ingredients in prepared feeds for many species of fish and livestock as a result of its protein density, unique balance of amino acids, high digestibility and effect on palatability of the complete feed. To address supply limitations and the unstable cost of fish meal, many studies have been conducted with alternative protein sources to replace fish meals in diets for most commercially grown species of fish. Performance of fishes when fed these alternative protein feeds is dependent upon the natural diet of the species fed, composition and nutrient availability of the test ingredient, possible presence and level of anti-nutritional factors, and effect on the palatability and pellet stability of the prepared feed. Animal meals are typically higher in protein and lower in carbohydrate concentration compared to those from plant origin.

One of the obvious short-comings of research to date is that studies on substitution of fish meal and fish oil have been mutually exclusive. Many of the promising results from substitution of fish oils with plant oils have been due, in part, to inclusion of high levels of fish meal in the same diet. The fish meal provides some of the essential fatty acids that would have normally been provided directly by the fish oil. Although other novel sources of essential fatty acids are available, they must become more economical before they can sustain the needs of the aquaculture industry. Nevertheless, great advances in reducing, if not eliminating, the reliance upon wild fisheries resources for aquaculture feed ingredients are being made.

Action

A manuscript will be submitted during the intersession for publication in a peer reviewed scientific journal.

6 ToR D - Further investigate fouling hazards associated with the physical structures used in Mariculture and assess their potential for the introduction of invasive/nuisance species into the local environment

Structure associated with mariculture activities can provide considerable surface area for increasing the colonization of local species or species not typically found in the culture area, leading to nuisance or pest levels. This is presumably due to the increased habitat complexity and appropriate substrate for epifaunal organisms with nuisance abilities. The question is raised, do these structures and their functions have the potential to provide a pathway for the introduction of an exotic species or the proliferation of native fouling species to the point of becoming a nuisance in a system or potentially spread over a larger geographical area once established. The tunicate infestation on mussel farms in PEI, Canada could provide an opportunity to examine the mechanisms implicated in the progression from the introduction/presence of a fouling species to an invasive level or nuisance level, as it pertains to farming structures and functions. The management implications in term of farming intensity and potential mitigation strategies to control the population level of fouling species need to be investigated and developed to reduce the impact of fouling organisms on the sustainability of the farming activities and their potential environmental impacts.

The concept of Integrated Pest Management (IPM) has been applied in terrestrial settings, such as agriculture, for some time. IPM refers to a system of managing pests through a wide variety of management practices and control measures that are environmentally sound and economically feasible for the farmer. Typically, IPM uses husbandry, physical, chemical and biological methods to reduce populations of pests, whose control has traditionally relied on extensive use of chemical or mechanical treatment. Although the main objective of IPM in the agricultural setting is to keep the population density of pest species below the level that causes economic loss, in the mariculture setting, it will need to be broadened to an ecosystem level. As an example, Dumbauld *et al.* (2006) have recently outlined and updated a long-standing IPM plan for two (native) burrowing shrimp in bottom culture of oysters in the state of Washington. IPM systems have three important components: 1) information collection, 2) threshold identification, and 3) control measures. This approach requires a thorough knowledge of a fouling species life history and population dynamics as well as an understanding of its interaction with farming practices and environmental or ecological conditions. For example, information on the life history and population dynamics of a fouling or pest organism could lead to control measures aiming at reducing the reproduction potential of organisms found on culture structure, either by reducing the overall density or strategically reducing the population during optimal reproductive periods. Similarly, information on farming intensity, such as the density of physical structures, and crop rotations could play an important role in the management of fouling or pest organisms, by reducing their reproductive capacity. This approach emphasizes management rather than eradication (Lafferty & Kuris 1996). This section reviews the scientific literature on the management of fouling organism in mariculture with special attention on exotic species, identifies research needs to this end, and recommends standardized monitoring approaches to better detect and understand the impacts of fouling organisms.

6.1 Research needs for mitigation

It is well known that artificial structures, such as aquaculture facilities, serve as vectors for the dispersal of marine exotic species by providing habitat or facilitating their transport (Carlton 1992). Because of the importance of exotic species in aquaculture, much work has been directed towards developing management tools for limiting their impact (see reviews in ICES 2006, McKindsey *et al.* in press). However, most of this research to date has concentrated on direct mitigation (i.e., methods to remove fouling species from product and culture-related structures). Indeed, most work to date on control or eradication of exotic marine species has been focused on biocides or physical control methods (Thresher & Kuris 2004). Little work has concentrated on more holistic ways of addressing the proliferation of exotic (and other) species. Such issues include farming practices and using knowledge of their biology and ecology to design mitigation strategies.

Bax *et al.* (2001) outline a framework with seven steps for controlling exotic species in marine systems. These are 1) establish the nature and magnitude of the problem; 2) set and clarify objectives; 3) consider all alternatives (of all possible actions); 4) determine risks of actions; 5) reduce risk of any action (may include experimental trials and monitoring); 6) assess benefit and risk of full-scale implementation (includes full-scale implementation); and 7) monitor results. Of course, all of this is to be done in consultation with stakeholders at every step, evaluating all costs and benefits as well as legal ramifications, and requires biological and other information to inform the process. The process should be outlined a priori within a rapid response plan that assigns responsibilities to different agencies, ensures adequate funding, and has sorted out legal issues. Of importance, there is often a negative correlation between the acceptability of a given management response and its perceived effectiveness; that is, the more a effective a treatment is perceived to be, the less acceptable it is (Thresher & Kuris 2004).

The overwhelming conclusion from most studies and reviews on management strategies for exotic species in general is that responses to appearances of an exotic species should be done as quickly as possible (e.g., Bax *et al.* 2001, Simberloff 2003, Lodge *et al.* 2006). Failing that, management options, especially eradication, are less likely, or at least perceived to be less likely, to be effective (Thresher & Kuris 2004). In these cases, farm management strategies are considered to be the only economically viable solution (Bourque *et al.* 2003). Here, we address research needs with respect to the mitigation of exotic species associated with bivalve aquaculture, focussing on farming/husbandry practices and using knowledge of their biology and ecology to design mitigation strategies.

There are a number of strategies based on the biology and/or ecology of exotic species that may be considered. First, population biology principles may be used to determine densities below which populations are less able to reproduce effectively. As exotics are often tightly associated with the physical and/or biological structure of aquaculture structures, reducing their abundance below some critical threshold may be sufficient to keep their numbers below a nuisance level or even eradicate populations, as was shown for an exotic polychaete infesting abalone and other local gastropods in California (Culver & Kuris 2000). Although this example is for a species with benthic larvae, the same may also be true for species with short larval stages, such as tunicates, or even those with long planktonic stages (Culver & Kuris 2000). However, McCallum *et al.* (2004) warn that most population epidemiological models are based on terrestrial organisms with great dispersal, which may not be the case for pests in the marine system, such as tunicates, and that marine systems may behave differently. For example, starfish gathering around mussel lines have been shown to have increased reproductive output and fertilization success (Inglis & Gust 2003). Just as this may have a positive impact on starfish populations, decreasing the density of other broadcast spawners may similarly decrease reproductive success and impact local populations.

Second, a number of biological control strategies have been suggested to control exotic species in marine systems (Lafferty & Kuris 1996). According to Hoddle (2004), once prevention, containment, and eradication options have been exhausted or deemed infeasible, the use of biological control strategies may be the only feasible way to control exotic species. This includes the augmentation of native predators or parasites and the introduction of the exotic predators, parasites or diseases, or else viruses (see Thresher & Kuris 2004). Some initial success has been shown with respect to invasive tunicates in mussel culture in Prince Edward Island, eastern Canada, where native rock crab populations were augmented to predate on *Ciona intestinalis* (Landry, pers. obs.). However, there are many issues with respect to the safety of this option as the augmented or introduced "control" species are not always perfectly host specific and the cure may at times be worse than the initial problem (Secord 2003). Recent attempts to establish rules for risk assessments to prevent negative impacts from any biological control strategies (Messing & Wright 2006) may limit the chance of such ancillary problems.

Third, biological control may also include the use of genetically modified organisms. These include modifications of the exotic species itself (such as sterile males or less fit individuals), of native species, or of viruses or diseases (Thresher & Kuris 2004).

There is a caveat to the importance of having good quality biological information before acting to eradicate or otherwise control a given exotic species. In the worst case scenario, a lack of such information can be used as an excuse for inaction, even though a quick decisive action may have been sufficient to eradicate an introduced species (Simberloff 2003). This has shown to be the case for a variety of taxa, including the algae *Caulerpa taxifolia* (Anderson 2005) and the Caribbean black-striped mussel *Mytilopsis sallei* (Bax *et al*. 2001). However, once the opportunity for rapid response has passed, Simberloff (2003) suggests that biological and ecological knowledge become more important and management rather than eradication is the more likely option. Similarly, Thresher & Kuris (2004) suggest that there are less management options as exotics become more wide-spread. A recent workshop of specialists suggested that some control options (the use of exotic predators and viruses or genetically-modified diseases or viruses) are simply not acceptable under any circumstances (Thresher & Kuris 2004). Of the other options considered, genetic modification of exotics to reduce their viability seems to be the one with the most potential.

Husbandry practices also need to be considered as potential mitigation measures. Among the most common include exposing culture structure to unfavourable environmental (air (desiccation), turbidity or temperature) or handling conditions (socking and resocking schedules, harvesting schedules, placement – including spacing and depth, fallowing, etc.). For example, mussel farms in Toranto, Italy, hang the mussel socks outside the water to reduce fouling through desiccation. In PEI, mussel farmers lower their mussel socks to the bottom to increased crab predation on fouling organism. In Spain, re-socking mussel after an initial nursery phase, eliminate the first set of fouling organism reducing the growth period of a new set of foulers to <12 months, prior to harvesting. Other modifications in husbandry practices may provide additional mitigation measures, without direct treatment. All of these together form the basis of an efficient IPM. These will be discussed at a future WGEIM meeting.

6.2 Varia (human and financial resources and legal issues)

One subject that must be addressed early in the rapid response (and other longer-term management strategies) is the issue of who pays. It is typically far less costly to address issues as soon as they become apparent rather than later on in the invasion process. For example, the eradication of the sabellid polychaete in California cost approximately US$5100 (US$3800 in labour) as well as 3750 hours of volunteer labour (Culver & Kuris 2000). Similarly, the eradication of *Caulerpa taxifolia* in the same state was only possible because the invasion was deemed to be tantamount to an oil spill, thus freeing up emergency funding (Anderson 2005). In the same case, human resources were already in place (both professional and volunteer) to enable the operation. Without such an operation, the situation may have degraded to that observed in the Mediterranean which is most likely impossible to remediate at this time because of the lack of initial reaction to the introduction of this same species.

As suggested above, perhaps of greatest importance in this exercise is the establishment of clear roles and responsibilities (structural, financial and legal) for all potential participants. These must be defined so that emergency preparation and planning may move forward.

In the same spirit of community collaboration and coordination for eradication of exotic species, the same collective efforts from mariculture operators, may be essential for effective management of a nuisance species or pest within an infested area as well as surrounding areas. Mitigation measures applied in one farm may provide minimum success unless it is equally applied, or at least coordinated with the mitigation measures of neighbouring infested farms. This main benefit of coordinated mitigation approach is in reducing the overall reproductive potential of the exotic or nuisance species. Apart from the financial implication and the appropriation (buy-in) of various marine users, the main obstacles in achieving optimal results remain the basic biological knowledge and the monitoring capacity.

6.3 Monitoring

Monitoring and data gathering activities on Aquatic Invasive Species (AIS) and aquatic pest in the marine environment has been increasing over the past decade. Australia is recognized as a leader in this field, possibly because of their higher susceptibility to ecological and economic impacts of invasions by aquatic exotic species and their substantial history with terrestrial invasive species. In New Zealand, North America and most of the European countries, monitoring and data gathering on marine AIS has been inconsistent and limited, and may only be starting to get the attention it deserves, particularly in terms of their potential impacts on the growing mariculture industry.

In Australia, a national port survey program has been developed to document the occurrence of non-indigenous species in >75 Australian ports, which can receives a total of > 10000 ship visits per year. This program consists of a standardized set of survey methods to ensure consistency in the assessments of introduced species status at each surveyed port. This survey programs concentrates on specific target pest species (see CRIMP, http://crimp.marine.csiro.au) (Hewitt & Martin 2001). Shoreline habitats such as salt marshes, mangroves and beach and dune areas are also considered in this survey program. Monitoring and re-surveying protocols were also developed. Although protocols for re-surveying are complex and require a cost-benefit analysis, the current recommendations for re-surveying is every three to five years. Monitoring efforts are recommended when 1) finding a targeted 'pest' species at low densities or in limited distribution 2) identifying toxic dinoflagellate cysts in the sediments, or 3) to determine the spread of a established target 'pest' species in adjacent or frequent trading domestic port. Monitoring frequency varies, but is recommended at a minimum of 4 times a year (i.e. summer, autumn, winter and spring). Recommended methodologies include a minimum of 15 collectors per site and the use of various collector types for different invaders, such as fouling panel collectors for hard substrate species, traps for mobile epifauna and settlement trays for soft sediment infauna. Some monitoring activities are supported through organization and management of volunteers within community-based groups, mainly for macroscopic species. Volunteers need to operate under appropriate State of the Environment standard operating procedures.

The National Introduced Marine Pest Information System (NIMPIS) was developed as a data gathering and management system. It provides managers, researchers, students and the general public with access to accurate and up to date information on the biology, ecology and distribution of introduced marine species, as well as potential control options for those designated as pests. This system addresses 1) species that have already been introduced to Australian waters and 2) new species that pose the highest threat (Hewitt *et al*. 2002).

In Tasmania, a specific pest monitoring program was developed and evaluated for the mariculture industry in conjunction with the Tasmanian Marine Farm Monitoring Project. This trial program aims to raise awareness of marine pest issues in the marine farming sector in SE Tasmania while assessing the potential for involving marine farmers in the early detection of marine pest incursions. The development and maintenance of this monitoring capacity is ongoing with a focus on a pest awareness program targeted at the marine farming sector, with limited ongoing support to provide assistance for species identification and feedback on the outcomes of the monitoring program.

In New-Zealand, the monitoring activities for marine invaders are lead by MFish with the goal of minimizing the risks to marine environment from biosecurity threats, through the powers of the Biosecurity Act 1993. Although MFish has no operational capability in marine biosecurity, its aim is to 1) develop and monitor strict compliance regimes for ballast water discharge 2) undertake baseline monitoring of major ports, 3) develop a wider surveillance network for new and undesirable marine organisms, and 4) manage a surveillance scheme for some species. Operational services are contracted from other agencies.

In North America and Europe, monitoring programs for marine invaders and pests are at various stages of development and vary considerably in their objectives and methods.

In Atlantic Canada, efforts to develop a standard monitoring approach for marine invaders are being undertaken. Elements of this monitoring program are being standardized to on-going monitoring activities from various parts of the world, but with limited coordination among neighbouring jurisdictions. Broadly, it is a 3-tier approach for monitoring for exotic aquatic species: 1) Level 1 – Low frequency, wide geographic coverage, and direct, non-targeted sampling (i.e., determining all species present), such as the navigational buoy monitoring; 2) Level 2 – High frequency, low geographic coverage (i.e., target sites such as ports, marinas, etc), directed sampling (i.e., targeting specific exotic species, not complete inventories), such as using collector plates and targeted sampling; 3) Level 3 - High frequency, local scale, indirect sampling for target species using public outreach, community involvement. A total of 10 target species is suggested for Level 3 monitoring.

6.4 References

Anderson LWJ (2005) California's reaction to *Caulerpa taxifolia*: a model for invasive species rapid response. Biol Invasions 7:1003–1016

Bax N, Carlton JT, Mathews-Amos A, Haedrich RL, Howarth FG, Purcell JE, Rieser A, Gray A (2001) The control of biological invasions in the world's oceans. Conserv Biol 15:1234-1246

Bourque D, Landry T, Davidson J, McNair N (2003) Impact of an invasive tunicate in Atlantic Canada: Recruitment and competition. J Shellfish Res 22:320

Carlton JT (1992) Dispersal of living organisms into aquatic ecosystems as mediated by aquaculture and fisheries activities. In: Rosenfield A, Mann R (eds) Dispersal of living organisms into aquatic ecosystems. Maryland Sea Grant, College Park, p 13-46

Culver CS, Kuris AM (2000) The apparent eradication of a locally established introduced marine pest. Biol Invasions 2:245-253

Dumbauld BR, Booth S, Cheney D, Suhrbier A, Beltran H (2006) An integrated pest management program for burrowing shrimp control in oyster aquaculture. Aquaculture 261:976-992

Hewitt JE, Martin RB (2001) Revised protocols for baseline port surveys for introduced marine species: survey design, sampling protocols, and specemin handling. Report No. 22, Centre for Research on Introduced Marine Pests, Hobart

Hoddle MS (2004) Restoring balance: using exotic species to control invasive exotic species. Conserv Biol 18:38-49

ICES (2006) Report of the Working Group on Environmental Interactions of Mariculture. ICES CM 2006/MCC:03. p. iii + 195, ICES, Copenhagen

Inglis GJ, Gust N (2003) Potential indirect effects of shellfish culture on the reproductive success of benthic predators. J Appl Ecol 40:1077-1089

Lafferty KD, Kuris A (1996) Biological control of marine pests. Ecology 77:1989-2000

Lodge DM, Williams S, MacIsaac HJ, Hayes KR, Leung B, Reichard S, Mack RN, Moyle PB, Smith M, Andow DA, Carlton JT, McMichael A (2006) Biological invasions: recommendations for U.S. policy and management. Ecological Applications 16:2035–2054

McCallum HI, Kuris A, Harvell CD, Lafferty KD, Smith GW, Porter J (2004) Does terrestrial epidemiology apply to marine systems? Trends Ecol Evol 19:585-591

McKindsey CW, Landry T, O'Beirn FX, Davies IM (in press) Bivalve aquaculture and exotic species: a review of ecological considerations and management issues. J Shellfish Res

Messing RH, Wright MG (2006) Biological control of invasive species: solution or pollution? Front Ecol Environ 3:132-140

Secord D (2003) Biological control of marine invasive species: cautionary tales and land-based lessons. Biol Invasions 5:117-131

Simberloff D (2003) How much information on population biology is needed to manage introduced species? . Conserv Biol 17:83-92

Thresher RE, Kuris A (2004) Options for managing invasive marine species. Biol Invasions 6:295-300

7 ToR E - Review the role and tasks of WGEIM in relation to ICES Strategic Plan and action plan as well as the key tasks of the Mariculture Committee and prepare a draft future work plan

7.1 Review of Terms of Reference between 2003-2007

The goal of this exercise was to examine the relevance of topics covered by the Terms of Reference for WGEIM to the current ICES Strategic Plan [1]. This exercise comprises two portions whereby ToRs addressed by WGEIM during in the period covered by the ICES Strategic Plan 2003-2007 were reviewed in light of the Action points from that Plan and a commentary was provided on the output and status of the ToR. The second portion of the exercise encompassed the identification of emerging issues related to environmental interactions of mariculture with an assessment of their relevance to the Strategic Plan 2003-2007 as well as the new ICES goals, outlined in the Draft ICES Marine Science Strategy Plan [2]. The review of previous ToRs is presented primarily in a tabular form (Table 1). The table comprises; a list of the specific subject areas, the relevant ICES goal and action points within those goals and a commentary on the progress made by the group in addressing the issue as well as the current status of the ToR. Of the twelve subject areas covered by the group in the last five years, seven have been completed in a satisfactory fashion, three have been carried over as recurring ToRs for future meetings of the group, while two were transferred to the new group on Integrated Coastal Zone Management (WGICZM). Other future ToRs have evolved from some already considered completed.

There are strong links between WGEIM and WGMASC and this collaboration extends to the co-sponsorship of theme session at ICES ASC 2008 in Halifax, Canada on the subject of Ecological Carrying Capacity in Aquaculture.

The group has published an average of 1 publication in peer-reviewed journals in each of last three years with plans to publish further (Table 1). For example, in 2007, the group plans a series of publications (6 papers) relating to the development of Risk Analysis in mariculture (ToR 1-Table 1), in addition to a review of alternative feeds in aquaculture (1 paper; ToR 10-Table 1).

Collaborations with other agencies (e.g. FAO GESAMP Working Group 31) have taken place and discussions are ongoing to conduct the WGEIM meeting in 2008 jointly with the North Pacific Marine Science Organization (PICES) following preliminary discussions held between a WGEIM member Dr. Edward Black and colleagues at PICES (Alex Bychkov and Michael Rust). The goal of this meeting would be to discuss mariculture issues of mutual interest while emphasising environmental interactions. Some topics of common interest include:

- Sustainable development - the precautionary approach, uncertainty and risk assessment/risk analysis.
- Exotic species
- How good is our ability to predict far-field effects and carrying capacity.

Collaboration among members of the group outside the remit of ICES has resulted in fruitful research and exchange opportunities. A number of members (H. Thetmeyer and W. Silvert) are involved in EU FP6 funded ECASA [3] project, which has focused on identifying suitable impact indicators relating to aquaculture. Student exchange has occurred between Canada (C.

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1 The ICES Action Plan, 2003-2007: Adopted by Council on 28 October 2002

2 Draft ICES Marine Science Strategy Plan. Report of the Bureau Working Group on Updating the ICES Strategic Plan. February 2007

3 www.ecasa.org

McKindsey) and Ireland (F. O'Beirn) with a graduate student conducted a review and comparison of the mariculture licensing arrangements within the two countries. Close co-operation has resulted between members from Ireland (F. O'Beirn, T. McMahon) and the UK (I. Davies) on the implementation of the WFD and on operational matters relating to the licensing of aquaculture in these two jurisdictions. Other collaborations have included, members of the group reviewing programs in the country of other members, e.g., B. Costa-Pierce (USA) and F. O'Beirn (Ireland) have reviewed DFO-Canada programs and projects.

Table 1. Progress review of the ToRs covered by WGEIM during the period 2003-2007. Shaded ToRs are active and are currently being considered by the working Group.

Terms of Reference Considered by WGEIM in period 2003-2007		*ICES Goals*[1]	*Relevant Action Points*[3]	*Progress and Status*
1	Prepare a publication on a standard protocol detailing the Risk Analysis on the potential impacts of escaped aquaculture marine (non-salmonid) finfish species on local native wild stocks and carry out case studies of risk analyses of escapes of non-salmonid farmed fish (cod, sea bass, sea bream, halibut, turbot).	**2** **3** **4** **6**	**2.5; 2.6** **3.3** **4.6; 4.7** **6.3**	**Progress:** This term of reference has been a major subject for WGEIM since 2003. It has progressed well since with an output of an overview template paper and 5 case studies to be submitted as a package for publication in the Journal Aquaculture during 2007. **Status**: The working group considered that this ToR was completed in a satisfactory fashion.
2	Work with joint ICES/FAO GESAMP WG 31 to develop aquaculture risk analysis methodologies.	**2** **3** **4** **5**	**2.10;** **3.3; 3.9; 3.14** **4.6; 4.7** **5.14; 5.16**	**Progress:** Numerous members of WGEIM participated in this working group and contributed to the broader exercise. Good synergies between the groups was achieved. A report produced by the GESAMP Group will be published shortly. **Status**: This ToR was completed in a satisfactory fashion..
3	Update the report on developments in implementation of EU Water Framework Directive, the EU Strategy for sustainable aquaculture and EU Marine Strategy.	**2** **3** **4**	**2.5** **3.3;** **4.6; 4.8; 4.14**	**Progress:** This was considered a useful exercise that should be revisited by the group as the implications of these and other legislation becomes clearer. Issues highlighted by this ToR were utilized by ACME in subsequent reports. **Status**: This ToR was completed in a satisfactory fashion and may be revisited by the group...
4	Evaluate the recent developments over the last five years in carrying capacity models for shellfish with a view to proposing an ICES theme session or co-sponsored symposium in this area	**1** **2** **3** **5** **6**	**1.3; 1.5** **2.12** **3.4; 3.6; 3.9** **5.15** **6.3**	**Progress:** This review identified some important considerations in the development of carrying capacity models for shellfish culture. A publication was prepared, submitted and accepted in the Journal Aquaculture[2]. A joint session between WGEIM and WGMASC on ecological carrying capacity is scheduled ASC in 2008. **Status:** The ToR was completed in a satisfactory fashion. The progress on the joint-session at ASC will be reported upon in future reports.

1 The ICES Action Plan, 2003–2007: Adopted by Council on 28 October 2002

2 McKindsey, C., H. Thetmeyer, T. Landry and W. Silvert. 2006. Review of recent carrying capacity models for bivalve culture and recommendations for research and management. Aquaculture 261: 451-462

	Terms of Reference Considered by WGEIM in period 2003-2007	*ICES Goals*[1]	*Relevant Action Points*[3]	*Progress and Status*
5	Formulate a strategy to protect aquaculture against the harmful effects of external influences (e.g., contaminants, habitat alterations) arising from other resource users and their environmental impacts, with the aim of gaining better cooperation in developing modern tools to prevent or mitigate negative interactions.	**2** **4**	**2.2; 2.8; 2.10** **2.11; 2.13** **4.14; 4.15**	**Progress:** A short summary was prepared on the application of ICZM to protect mariculture from effects of other activities in the marine environment. **Status:** This ToR was transferred to the newly formed Study Group on Integrated Coastal Zone Management.
6	Prepare a report on an evaluation of existing Decision Support Systems (DSS) tools, GIS and other expert systems in order to derive strategic advice on the content of a DSS for mariculture, and also to identify potential linkages to existing tools presently being developed, tested or already used in coastal management schemes	**2** **3** **4**	**2.2** **3.3; 3.6** **4.7; 4.11**	**Progress:** A short report was prepared by WGEIM within which terminology was defined and issues were discussed. **Status:** This ToR was not revisited but issues raised were dealt with in other ToRs of the group (e.g. ToR 1 & 8) and the SGICZM.
7	Conduct an analysis of the literature and research on the current bath treatments and in-feed additives (treatments) used to treat salmon for sea-lice, and produce a synthesis (state of knowledge) on their fate in the near and far field environment and their effects on non-target organisms (e.g., crustaceans and invertebrates).	**2** **3** **4** **6**	**2.7; 2.8** **3.14** **4.9** **6.3**	**Progress:** A comprehensive review was completed and published. **3** A second publication from this work is awaiting final edits for the ICES Cooperative Series Report. **Status:** This ToR was completed in a satisfactory fashion.

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3 K. Haya, L. E. Burridge, I. M. Davies and A. Ervik. 2005. A review and assessment of environmental risk of chemicals used for the treatment of sea lice infestations of cultured salmon. in The Handbook of Environmental Chemistry (Editor in Chief: O. Hutzinger), Volume 5, Water Pollution and Environmental Effects of Marine Finfish Aquaculture, Volume editor: Barry Hargrave, Springer-Verlag, Berlin.

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Terms of Reference Considered by WGEIM in period 2003-2007		ICES Goals[1]	Relevant Action Points[3]	Progress and Status
8	Evaluate examples of sustainability indices proposed for mariculture operations and provide specific recommendations on their utility. Consider and evaluate the possibility for developing a "sustainability index" concerning environmental interactions of mariculture	**1** **2** **3** **4**	**1.11** **2.2; 2.6** **3.5; 3.7; 3.9** **3.1; 3.12** **4.6; 4.7; 4.15**	**Progress:** A draft paper has been produced reviewing the criteria for sustainable indices for mariculture with recommendations. Additional information will be incorporated for WGEIM 2008. **Status:** Satisfactory progress has been made on this ToR.
9	Consider and evaluate the current state of development of integrated culture systems (e.g., fish –invertebrate – seaweed co-culture) with a view to assessing the potential of polyculture to mitigate the environmental effects of mariculture and subsequently provide recommendations on changes to regulatory frameworks that are required to accommodate this form of aquaculture operation.	**2** **3**	**2.6; 2.12** **3.10; 3.11** **3.12; 3.14**	**Progress:** This ToR will be revisited at WGEIM 2008. **Status:** Satisfactory progress has been made on this ToR.
10	Assess and report on the state of knowledge of alternatives to fish for use in formulated feeds for finfish aquaculture	**3** **6**	**3.8; 3.14** **6.3**	**Progress:** This ToR was completed in WGEIM 2007 and will be submitted during 2007 for publication to the Journal Aquaculture. **Status:** This ToR was completed in a satisfactory fashion.
11	Investigate fouling hazards associated with the physical structures used in Mariculture and assess their potential for the introduction of invasive/nuisance species into the local environment.	**1** **2** **3** **6**	**1.2** **2.5; 2.6; 2.10** **3.11** **6.3**	**Progress:** A review was carried out on the potential of mariculture structures and activities to facilitate the spread of nuisance or exotic species. The review was submitted and accepted for publication in Journal of Shellfish Research[4]. **Status:** This ToR was completed in a satisfactory fashion. However, it has been modified to address some of the issues raised and will be carried forward.

4 McKindsey, C.W., T. Landry, F. X. O'Beirn, I. M. Davies. 2007. Bivalve aquaculture and exotic species: a review of ecological considerations and management issues. Journal of Shellfish Research

7.2 Emerging Issues relating to Environmental Interactions of Mariculture

Given the importance of mariculture in the ICES and global environments, a second part of this exercise consisted of the identification of a number of emerging issues involving environmental interactions of mariculture which could form the basis of recommendations to MARC for future ToRs of WGEIM or other working groups.

All of the science related goals (goals 1-5) in the ICES Action plan 2003-2007 have been reflected in the ToRs covered by WGEIM. It is also clear that WGEIM has consistently contributed to many of the goals relating to outreach, publication and co-operation with other agencies. These goals and sub-actions of the Action Plan have helped to provide the context within which to develop the work plan of WGEIM.

ICES is in the process of developing strategic documents to guide its work over the next years. However, development of the New ICES Action Plan has not yet reached the stage of definition of specific subcategories to the overall Goals. Consequently, it is not possible to allocate the emerging and important issues in mariculture identified by WGEIM to detailed aspects of the New Action Plan, but only tentatively to the more general Goals, and back to the Goals in the 2003-2007 Plan.

Table 2 lists emerging issues relating to environmental interactions of mariculture. These issues are further expanded in the text below. The list is not exhaustive, and only represents the views of the members attending WGEIM 2007. Some have foundation in the existing action plan (2003-2007) and this is noted. Others are novel and have as yet to be considered for future action points.

Table 2. A list of issues relating to Environmental interactions of Mariculture and their relevance to the old and new (draft) ICES actions plans and proposed themes to considered within subsequent reviews. Legend: MSP – Marine Spatial Planning; CC – Climate Change; SA – Sustainability of Activity

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,

7.3 Summary of Emerging Issues (in no order of priority)

ICES have acknowledged that the numerous options that consider sustainability of marine-related industries are all intrinsically multi-disciplinary. Providing the scientific basis for selecting indicators of ecosystem status, and for evaluating the performance of such ecosystem metrics, will require an effective mix of physical, chemical, and biological oceanographers, fisheries and marine biologists, fishing technologists, quantitative experts, and others. Of particular importance will be the ability of indicators to be communicated across disciplines and objectives. An additional core task, identified by ICES, is to unravel the impacts of human uses of the seas, including exploitation of its living resources, and impacts of climate variability and climate change on marine ecosystems and their components. Finally, research to advance mariculture techniques in an environmentally sound manner and within the framework provided by other users in the marine environment also provides challenges. All human activities that depend on, and affect, marine ecosystems, have social and economic consequences that need to be better understood.

As a consequence of these goals and tasks identified by ICES it is clear that three broad subject areas can be defined that have relevance to the work of WGEIM. WGEIM consider these broad themes important from a global perspective. The broad themes are;

- Sustainability of activities (SA)
- Climate Change (CC) and,

- Marine Spatial Planning (MSP).

All future ToRs generated by the working group shall either directly address these as subject areas or shall consider the specific questions from the perspective of one or a combination of these themes.

Integrated multi-trophic aquaculture systems

Integrated aquaculture systems (multi-trophic-species systems) offer possible ways to utilise the waste materials from the primary species being farmed to create additional products of significant commercial value while reducing the overall environmental impacts of the site. Examples are the utilisation of soluble nutrients released by fish farms by adjacent macro-algae production, while the particulate wastes can be extracted by bivalve molluscs. Some practical developments are starting to occur, and the EU has supported work in this area. However, the benefits do need to be fully elucidated for both open and closed systems. The efficient use of resources (including space), the ability to increase financial return and the potential mitigation capabilities that multi-trophic culture might confer upon each species are some of the drivers underlying the development of integrated multi-trophic aquaculture systems. Currently WGEIM is in the process of evaluating the environmental impacts of integrated (multi-trophic) culture systems and will provide recommendations on changes to regulatory frameworks that might be required to accommodate this form of aquaculture operation.

Recommendation to MARC/ICES

WGEIM recommends that a review of existing IMTA programs and specific projects continues as a Term of Reference for WGEIM 2008.

Influence of Climate Change on mariculture systems

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, Aberdeen[1] (Annex 6) 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.

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

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.

The application of Risk Analysis to new mariculture species or practices

WGEIM has developed (in conjunction with FAO GESAMP, see ToR A) an over-arching protocol for the risk analyses of activities related to mariculture applications. While the case studies have focused to date upon the escape of selected finfish species from cultivation, the application to the introduction and escape of shellfish species has not been carried out. The continued development of practical and easily applied RA methodologies is imperative given the continued change of drivers e.g. scale of influence and operation, climate change, husbandry practices (organic products), genetic interactions and legislation changes.

Recommendation to MARC/ICES: The WGEIM recommends that the introduction of new species and husbandry techniques to mariculture should be accompanied by and a practical and appropriate risk assessment of the environmental risks and interactions.

Deep water, open ocean aquaculture.

As space in near-shore environments becomes limiting e.g., either for physical reasons, conflict with other users or visual intrusion, the need to explore other more isolated/off-shore locations to culture marine species has been highlighted and investigated in some circumstances. While engineering advances to deal with conditions and minimise impacts continue to be addressed, little attention has been given to a number of potential environmental interactions that might result from such activities. This issue might be addressed under a number of policy, regulatory and development drivers, including marine spatial planning (MSP), economic and environmental feasibility studies and foresight exercises to identify future issues. Specific issues that might be addressed include:

- Interactions with migratory species e.g. salmon.
- Risk Analysis
- Interaction with fisheries, particularly trawl fisheries.
- Visual impacts.
- Impacts on biodiversity
- Effects of structures as fish attraction devices.
- Navigational concerns and the increased chances of collisions with ocean going vessels resulting in potential escapes from cage culture systems.
- Industrial development directly related to health of industry, cost efficiency, MPA.
- Legal and jurisdiction constraints relating to location of structures, i.e., what binding regulations or jurisdiction applies (i.e. is it National, EU or UNCLOS) and how they might be adapted

Recommendation to MARC/ICES

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).

Management strategies for disease, pest and predators treatments in mariculture settings with special attention on ecosystem interactions

WGEIM 2005 completed a review of the impact of sea lice treatments. However, treatments and strategies to control other diseases, pest and predators are being developed and applied at a rate equal or greater to the growth rate of the mariculture industry with limited review on the interaction with ecosystems. Examples of issues that might be considered are the influence of vaccines on wild populations, bio-security, animal welfare and selective breeding. It would be informative to review current developments in order to document treaments and strategies deployed in mariculture operations to manage disease, pests and predators, as well as assessments of the environmental and ecological impacts of these practices.

Recommendation to MARC/ICES

WGEIM recommends that a review is conducted of; 1) documentation/publication listing the various treatments and strategies being used to control or manage diseases, pest and predators, 2) documentation/publication on the assessments of environmental and ecological interactions or impacts, and 3) recommendations on approaches and methodologies to assess the ecological interactions of existing and future treatments and strategies for diseases, pests and predators.

The interaction of mariculture and commercial fisheries.

The question of how mariculture will fulfil the shortfall and if there are implications of interactions use of commercial stocks for aquaculture purposes – extract of wild seed (e.g. mussels) for shellfish aquaculture, biological control of fouling organisms by commercial species e.g. rock crabs on tunicates in PEI, filtering of wild larvae by culture stocks, interactions with wild fisheries;

- Spreading of diseases and parasites (e.g. sea lice)
- Escapes
- Catching wild juveniles in some species fry production is not mastered, e.g. 1-year tuna capture for cage culture/ranching.
- Capture of wild eel juveniles for culture and/or re-stocking
- Sea ranching (e.g. scallops)
- Capture of mature females individual (e.g. cod in Canada, tuna and eels in Europe)

Recommendation to MARC/ICES

WGEIM recommends that the way fisheries and aquaculture can influence respectively their sustainability should be addressed.

Review of quality criteria of seed stocks used in mariculture

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.

Recommendation to MARC/ICES

WGEIM recommends a review be conducted on the use of seed stock quality criteria in mariculture and their applications in term of ecological performance.

Interactions between conservation and mariculture objectives.

The management of environmental impacts from mariculture can be based on policies that are difficult to interpret particularly as they relate to interactions with conservation driven objectives. ‘No net loss’, ‘habitat replacement’ and maintenance of ‘good conservation status’ are some of the terms used to govern management of traditional and mariculture activities in both North America and Europe. The ambiguity attached to these management objectives lead to confusion and has been described as an impediment to aquaculture development.

The upshot of all these situations and scenarios is that there is considerable confusion regarding the impact conservation goals might have on the management of mariculture activities and the potential for conflict of legislation is high. It would appear that a review of national policies and indices used to measure sustainability of mariculture (ToR B) should also include as a driver, i.e., legislative constraints, particularly those imposed by conservation related policies. From a more practical perspective the development of indices and subsequent setting of standards that have relevance to both the conservation objectives and mariculture management strategies, would seem to be an important end point.

Recommendation to MARC/ICES

WGEIM recommends to MARC that impact indices for mariculture activities be compared and resolved with those utilised to measure conservation status/goals and conclusions derived on their utility and recommendation provided on potential indices that may be utilised and easily applied by regulators of both sectors.

7.4 Summary and Conclusion

Underlying all the goals in the ICES Strategic Plan (both past and proposed) is a commitment to apply the precautionary approach in science and advisory work. In addition, ICES is committed to applying the principles of sustainable development when interpreting advisory products, for example in the restoration of fisheries and the subsequent exploitation at sustainable levels. Exploitation would provide a finite level of production for the market. However, market demand for fish already exceeds the supply from wild fisheries (noting that mariculture already contributes large quantities of fish protein to foodstuffs. Demands for fish as food in developing countries, or as a commercial venture, continue to increase and it is likely the further expansion of mariculture activities may contribute to filling that shortfall. Therefore, ICES must acknowledge the continued expansion of aquaculture activities in the marine environment, the continuous technical improvement of the sector, and how these activities interact with other marine related activities and impact on marine systems. Given that ICES is a major conveyor for advice in the marine sector, the continued inclusion of mariculture as a strong focus within the any future Action Plan is to be encouraged.

It is important to note that as mariculture develops its influence in the marine environment and should be considered comparable with fisheries and other sectors as players when discussing ecosystem approaches, sustainability concepts, precautionary approaches for which all the knowledge to address these issues is not readily available. As mariculture activities develop additional R&D will present a range of new interaction issues to be addressed, i.e., new species, new areas, new technologies, new products, new markets, additional issues for which basic knowledge may be lacking. Conversely, as marine aquaculture develops it will be exposed to increasing pressure from others developing activities in the marine environment.

ICES positioned to provide, interpret and, synthesize the best available knowledge to the policy markers on a range of issues relating to mariculture activities. It also well positioned to provide foresight for new research topics to be developed. In addition, advice originating from ICES may have global consequences as EU rules and regulations, informed by ICES advice, are very often adopted by non EU countries in order to market their products in EU members states.

WGEIM as a group has addressed a broad range of issues relating to mariculture. It is well balanced in terms of its representation from both North America and Europe. In addition, the group has published much of its reviews and output in the primary literature. The group has typically consisted of representatives of state agencies involved in both regulation and development of mariculture, in addition to academic representatives involved in both basic and applied research. While the group has had representatives from the mariculture industry participate in the past, WGEIM recommends that a more concerted effort be made to include industry and Non-Governmental Organisations (e.g. WWF, IUCN) representatives during the meetings, particularly when discussing matters germane to their particular interests. This would be consistent with the mechanisms of opening fisheries advisory and assessment meetings to both industry and NGO's. Interaction and participation from these sectors could take the form of one day or ½-day seminar workshop focusing the agenda item of interest and could greatly enhance to output of the group in terms of producing balanced advisory products. This promotion of this format for meetings would be entirely consistent with a number of the old[2] and proposed new[3] Action Plan goals. This strategy would also open the group to a range of additional skills some of which should be openly sought in order to progress specific terms of reference, e.g. socio-economic expertise to advise sustainability indictors of mariculture activities.

In addition to the recommendations detailed above in emerging issues **WGEIM recommends to ICES** that:

- Given the global importance of mariculture, it is important that ICES continue to include mariculture as a primary focus in future action plans.
- WGEIM broaden it 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.

2 Goal 5. Enhance collaboration with organisations, scientific programmes, and stakeholders (including the fishing industry) that are relevant to the ICES goals

Goal 7. Keep abreast of the needs and expectations of ICES Member Countries

Goal 8. Broaden the diversity of the scientists who participate in ICES activities

Goal 10. Make the scientific products of ICES more accessible to the public

3 Goal 2. Establish effective mechanisms of collaboration within ICES and with other (organizations etc.) to deliver and add value to ICES science and advisors programs.

Goal 3 - Plan and implement a program to deliver the advice decision makers need in partnership with Member Countries and Client Commission

8 Update on joint Session (with WGMASC) for ASC 2008 on Ecological Carrying capacity.

A theme session (chaired jointly by Francis O'Beirn (WGEIM) and Peter Cranford (WGMASC)) focusing upon the current state of assessing the ecological carrying capacity of marine systems was deferred from ASC 2007 (Helsinki) to that of ASC 2008 (Halifax). The International Conference on Shellfish Restoration is being held in the Netherlands in October 2007 and it was expected this might conflict with the ASC and that many expected participants would chose the ICSR meeting over a theme session in Helsinki. In order to progress the plans for the session in 2008, WGEIM members were asked to nominate individual scientists that might contribute to a session on ecological carrying capacity. A similar exercise was to be carried out by WGMASC. The goal would be to invite 15-20 scientists to participate with a view to having at least 10 talks contribute to the session

Action

WGEIM Chair to canvass members on prospective contributors to the WGEIM/WGMASC Joint –theme Session on Ecological Carrying capacity.

9 Discussion on Recommendations and new Terms of Reference

An issue was raised during the meeting regard in the workload at the meeting in terms of the number of subject areas to be dealt with and the number of delegates attending meetings in order to fulfil the obligations of the group. In order to address this it was suggested that either 1) the work of the Group be focused on ToR of the highest priorities, 2) attempts be made to bring in additional delegates from a variety of countries. It was recommended that the better option would be to increase participation to the group. In order to effect this it was agreed that a list of prospective Terms of Reference (or subject areas) be circulated to the current delegate list and they be asked to identify priority areas for discussion within the group and also whether they would be willing to lead or participate in the work relating to this ToR. This will ensure a broader participation in the selection of the ToRs beyond those present at the previous meeting and might stimulate greater participation in working group meetings. It must be noted that this exercise will not prejudice the completion of terms of reference currently being undertaken by the working group. For this reason the Terms of Reference listed in Annex 7 are an indicative list and are subject to change/confirmation by the group.

Recommendation

WGEIM Chair to canvass members by presenting a list of proposed Terms of reference for the working group and asking them to prioritise them in terms of importance and also identify what role they would take in progressing the ToR.

10 Location of next meeting

An invitation was received by Dr. Steven Cross, University of Victoria, British Columbia, Canada to host the next meeting. The dates of the meeting were set as April 14-18, 2008. The working group agreed this location and time. The meeting location was considered beneficial also in that a joint meeting be facilitated between WGEIM and PICES aquaculture interests. It is the stated goal of ICES to further develop joint activities with PICES in support of the ICES/PICES Memorandum of Understanding. These activities include joint working groups, and collaboration on projects in marine ecology and environmental processes, and on advancing our capacity to understand marine ecosystems, climate variability, and marine ecosystem impacts. As indicated above, extensive discussions have already occurred between a WGEIM member Dr. Edward Black and colleagues at PICES (Alex Bychkov and Michael

Rust) on the feasibility of a joint meeting. As a means of deriving as much out of the meeting as possible it was proposed that WGMASC be asked to hold their meeting at the same time (already agreed) and location. The Chair agreed to communicate with WGMASC in order to progress this request.

Action

The Chair is to communicate with PICES and WGMASC in order to coordinate a joint/overlapping meeting with the WGEIM during 2008 meeting in Victoria, British Columbia, Canada.

11 Nomination of Chair

The tenure of the current chair, Dr. Francis O'Beirn will be completed within 2007. A new Chair was sought from the participants of the group. In order to ensure smooth completion of some outstanding business, and the lead into the Theme Session at ASC 2008, it was agreed that the existing Chair should be invited to act as co-chair with Dr. Chris McKindsey for the 2008 meeting, after which Dr. McKindsey would serve as chair alone. A co-chair would be sought for the incumbent chair in 2010 and the process repeated.

Recommendation: WGEIM recommend that Drs. Francis O'Beirn and Chris McKindsey be appointed co-chairs of WGEIM for 2008.

12 Any other business and close of meeting

There was no other business to report. The meeting was closed on Friday April 20 at 11:30am by the Chair and special thanks was given to the host Dr. Helmut Thetmeyer and IFM-Geomar for hosting the meeting in such a fine fashion.

Annex 1: List of participants

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Annex 2: Agenda

Working Group on Environmental Interactions of Mariculture (WGEIM)

16-20 April 2007

IFM-GEOMAR, Kiel, Germany

Monday, 16 April

09:15 House-keeping and support arrangements – Helmut
09:30 Introduction of Participants -All
Review of Terms of Reference and Designation of Rapporteurs and drafting group members – Chair, All.
11:00 *Comfort Break*
11:30 Brief presentations and discussion on individual ToR from leaders:
ToR A – Risk Assessment – Ian
ToR B – Sustainability indices – Helmut
ToR C – Update on Alternative feeds – Kats
ToR D – Fouling hazards – Chris
ToR E – ICES Strategic plan - Francis
13:00 ***LUNCH***
14:00 Break out to drafting groups
15:00 *Comfort Break*
15:15 Return to Drafting Groups
16:45 Plenary – Progress update
17:00 end

Tuesday, 17 April

09:00 Plenary Session – overview of work to be carried out - All
09:15 Drafting groups reconvene
11:00 *Comfort Break*
11:30 Drafting groups reconvene
13:00 *LUNCH*
14:00 Drafting groups reconvene
15:00 *Comfort Break*
15:15 Drafting groups reconvene
16:45 Plenary – Progress update
17:00 end

Wednesday, 18 April

09:15 Plenary – Progress to report?
09:30 All Drafting groups reconvene
10:00 *Comfort Break*
10:30 Drafting groups reconvene
13:00 *LUNCH*
14:00 Drafting groups reconvene
15:00 Comfort Break
15:30 Progress distributed and read and discussed

Thursday, 19 April

09:15 Drafting groups reconvene
11:00 *Comfort Break*

11:30 Presentation of Progress and discussion; Leaders pass executive summary text, draft recommendations and 2005 ToR proposals to the Chair; Drafting of final document - groups reconvene
13:00 *LUNCH*
14:00 Field Trip to re-circulating facility in Büsum
19:00 Workshop meal in Büsum

Friday, 20 April

09:30

- Review Draft Summary Record
- Update on joint Session (with WGMASC) for ASC 2008 on Ecological Carrying capacity.
- Adoption of the scientific text of the report
- Discussion on Recommendations
- Discussion on new Terms of Reference
- Location of next meeting
- Nomination of Chair
- Any other business

12:00 End of 2007 meeting

LUNCH

Annex 3: WGEIM 2007 Terms of Reference

2006/2/MCC02 The **Working Group on Environmental Interactions of Mariculture** [WGEIM] (Chair F. O'Beirn, Ireland) will meet in Kiel, Germany, from 16–20 April 2007 to:

a) discuss the status of the risk assessment papers on non-salmonid mariculture species and the outcome of the GESAMP WG 31 meeting in November 2007;

b) further evaluate the examples of sustainability indices proposed for mariculture activities and critically evaluate those SIs recommended by WGEIM and other forums;

c) further the review on alternative feeds with a view to generating a manuscript to be submitted for publication in a peer reviewed scientific journal;

d) further investigate fouling hazards associated with the physical structures used in Mariculture and assess their potential for the introduction of invasive/nuisance species into the local environment;

e) review the role and tasks of WGEIM in relation to ICES Strategic Plan and action plan as well as the key tasks of the Mariculture Committee and prepare a draft future work plan.

f) evaluation of the environmental impacts of integrated (multi trophic culture systems and recommendations on changes to EU regulatory frameworks that are required to accommodate this form of aquaculture operation.

WGEIM will report by 15 May 2007 for the attention of the Mariculture Committee and ACME.

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	Action Plan references: a) 2.5, 2.6, 2.10, 3.3, 3.11 b) 2.2, 3.2, 3.3, 3.5, 3.12, 4.7, 5.3 c) 3.8, 3.9, 3.10, 3.11, 4.11.3 d) 1.2, 1.10, 2.11, 3.6 e) 7.1, 7.2, 8.1 **ToR a)** As identified previously by WGEIM, regulatory actions that limit the transportation and utilization of mariculture species can be viewed as a non-technical barrier to trade under international trade agreements. Risk analysis is one method of identifying environmental risks associated with the utilization of new species in culture and of justifying environmentally based constraints on the transfer and use of the species. GESAMP WG31 is developing methodologies for analyzing environmental risks associated with aquaculture activities. Their application to the environmental risks associated with culturing new mariculture species will enable better science-based management of existing resources and allow integration of aquaculture into the existing mix of coastal resource users for member states. WGEIM have produced 6 papers on this issues: one is an introductory paper that introduces the template for risk analysis followed by five case studies on five different aquaculture species. These papers are close to final condition and will be completed intercessionally and submitted for publication all together. An update will be provided at WGEIM 2007. Lead: Edward Black (Canada) **ToR b)** 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. This research will be reviewed and the utility of any indices proposed will be evaluated in light of the criteria for an acceptable sustainability index outlined by WGEIM 2005. Additional indices will be assessed with priority foucusing upon composite indices incorporating economic, environmental ans social aspects. The importance of multidisiciplinary approaches to defining sustainability will also be assessed. Lead: Barry Costa-Pierce, USA

	ToR c) WGEIM 2003 and other ICES group have previously reviewed this issue. However, the sustainability of utilising fish based oil in 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 and update on the progress in identifying alternatives to fish oil for feed in finfish aquaculture. Intercessional communication with industry sources and other working groups WGMAFC will be carried out and reported upon at the meeting. Lead: Kats Haya, Canada **ToR d)** 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 epifuanal organisms. The question is raised, do these structures have to potential to provide a pathway for the introduction of an exotic nuisance species to a system, which could potentially spread over larger geographical area once established. Existing examples will be examined and mechanisms elucidated more clearly. The management implications and potential mitigation strategies will also be addressed. This Tor will also be expanded to develop discussion document for consideration in 2007 to distribute it for consideration by other working groups (WGEIM, WGMASCV, WGITMO, SGBOSV, etc) on standardizing approach for monitoring these invasive species. The possibility of a new WG in this area will be discussed and a decision deferred until after the production of the WGEIM in 2007 and feedback from the other working groups. It was also suggested that WGEIM and WGMASC meet back to back in 2008 to collaborate via a combined plenary session to evaluate cross cutting issues. Lead: Chris McKindsey, Canada **ToR e)** To clearly identify the value of the topics covered in the WGEIM and ensure they are relevant to the ICES Strategic pan and action plans. More specifically, there are 10 goals outlined ICES Strategic plan and the relevance of the work of the group will be examined in light of these goals. The relevance of information emerging from WGEIM will be also assessed and it's relevance evaluated in light of the requirements of ICES client organisations or user groups. In addition, the products of WGEIM will be considered in relation to those of other ICES groups beyond the current mariculture groups so as to modify the integrated advice model currently being developed by ICES. Finally, this exercise will provide a fuller understanding of the working arrangements and outputs of the group such that is has clear relevance to marine management issues in each member state. Lead: Francis O'Beirn, Ireland **ToRf))** This Tor will be postponed by one year, until 2008, as there is currently a lot of scientific projects ongoing in this area which are due to report shortly and it would be benefical that this reports are considered prior to this ToR being tackled.
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	ACME
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

Annex 4: Executive summary of report on Integrated Risk Assessment and Communication For Environmental Interactions of Aquaculture

To effectively support an open and transparent approach to sustainable resource use, risk assessment and communication must be able to fit within a broader social, economic and environmental decision making framework, especially when uncertainty and the application of the precautionary principle are recognized as integral parts of that decision making environment. To support such a framework risk assessment and communication are presented in the integrated context of risk analysis. In developing risk assessment methodologies in this context it is clear that the communication aspects become paramount in enabling sustainable development in the modern open, inclusive and transparent type of resource allocation decision-making environment.

The objectives for risk analysis include:

1) **Integration into Sustainable Use Paradigms**: Risk assessment (a science-based assessment) must be integrated into a broader socio-economic decision making process to determine resource allocation for sustainable use. Risk analysis provides the basis for doing this through use of the table of levels of acceptable protection as well as a consistent and explicit mechanism for transparent application of the precautionary principle.

2) **Separation of Scientific Analysis From Valuation:** Risk assessment is a science-based analysis. In itself, it does not determine if a predicted outcome is good or bad, acceptable or unacceptable. Determination of these values can only occur when the predicted outcome is combined with social and economic information.

3) **Non-discrimination**: Comparable situations should not be treated differently and different situations should not be treated in the same way, unless there are objective grounds for doing so.

4) **Transparency**: To optimise the accuracy, effectiveness and social licence for aquaculture activities, risk communication must start early in the Risk Analysis process and communicate the information stakeholders and decision makers require in a manner they can utilize.

5) **Consistency**: Measures should be comparable in nature and scope with measures already taken in equivalent areas in which scientific data are available.

6) **Proportionality**: Risk management measures must not be disproportionate to the marginal change in risk and to the desired level of protection. It also must not aim for zero risk. Where the no hazard can be identified the risk assessment risk assessment should be concluded and evaluated as non-significant.

7) **Ongoing Monitoring of Predicted Effects**: Where ongoing monitoring is identified as a necessary component of risk management, the initial analysis must be considered as of a provisional nature. Availability of more reliable scientific data may lead to changes in our understanding of the mechanisms leading to environmental change and the level of risk (increased or decreased) associated with an aquaculture decrease. A requirement to monitor must be tied to a requirement of regulators to regularly report on the outcome of the monitoring.

The principles for risk assessment include:

1) Optimal management of risk can occur only where there is an open transparent and inclusive process that integrates of effective risk communication with hazard identification, risk assessment and risk management.

2) Implementation of risk management in a resource management scheme requires the output from an environmental assessment to be combined with economic and social values. These social and economic values should not be a part of a risk analysis or risk assessment protocol.

3) Valuation processes (e.g. establishing what is acceptable or not acceptable) are not part of risk assessment. Valuation is part of the socio-economic process.

4) It is the role of the resource allocator (usually a government official) to deliver a table of acceptable levels of protection for each endpoint. Technical staff undertaking the risk analysis should not be responsible for developing that/those table/s.

5) Acceptable levels of protection for each environmental change (as represented by a measurable endpoint parameter) must be created prior to undertaking a risk assessment.

6) Similar levels of acceptable protection should be applied to other human activities that could result in comparable environmental change comparable to those identified for aquaculture hazards.

7) A zero tolerance for potential environmental change is not acceptable in risk management.

8) Identification of a hazard should be based on evidence not opinion.

9) Each hazard should be identified along with the environmental change it might cause.

10) Each potential environmental change should have a measurable endpoint parameter identified that will quantify the severity of change.

11) The precautionary principle is incorporated in uses of risk management through adjustment of what constitutes an acceptable level of protection.

12) The effect of levels of uncertainty on the acceptable levels of protection table must be explicitly stated prior to undertaking a risk assessment.

13) Risk assessment is a science-based predictive process. It can be qualitative or quantitative. The predictive basis can be based on correlative information or on mechanistic models. Mechanistic models are preferable as there is less uncertainty and broader applicability across geographic regions.

14) Accurate assessment of the increased risk of environmental change due to a new activity (such as a new aqua-farm site) requires a clear understanding of other activities that might contribute to the same environmental change.

15) The risk assessment must present a transparent rationale for the degree of geographic overlap between the released hazard and the resource that might be affected.

16) Exposures (in a broad sense) should be kept as low as reasonably (cost-effective) achievable;

17) The temporal duration of the effect of the released hazard must be clearly enunciated, including the recovery time upon cessation of culture activities.

18) Development of a logic model that clearly communicates the extent and limits of our understanding of the mechanism by which environmental change occurs are essential to building an open and transparent risk analysis.

19) A cost/benefit analysis should be used to help establish when it is appropriate and feasible to undertake specific management of risk activities.

20) Where monitoring is determined to be a necessary component of Risk Management, regulators must commit to regular publishing of the results of that monitoring along with an analysis of whether to result alter the findings of the initial analysis.

21) No practice should be adopted by society unless it can be shown that the benefits outweigh the detrimental effects;

Objectives for risk communication are:

1) Offer stakeholders a sense of ownership of the process, and built trust in those conducting the exercise

2) Identify issues of concern and stakeholder priorities that need to be incorporated in risk identification and risk analysis

3) Ensure that user knowledge is effectively incorporated into the decision process

4) Provide a sound mechanisms by which stakeholders are informed about the nature and strength of causal relationships and the probabilities and uncertainties associated with the development

5) Guarantee that transparency of the entire risk analysis process leading to decision making is facilitated by effective exchange of information, and deals with perceptions, facts and uncertainty

6) Ensure that all pertinent and significant data required for the risk analysis are captured, not only from solid natural science disciplines that allow assessment environmental influence or change, but also incorporating stakeholder information on objectives, priorities and perceived risks

7) Provide the means so that any information generated as a result of the implementation of recommendations (e.g. for mitigation or additional research) arising from the risk analysis is also captured and further

8) Guarantee that the results of the risk analysis are communicated in a format that is clear and useful to individuals and organizations who use the information in their decision making processes.

The principles constructed to support those goals are:

1) Risk communication has to start at a very early date and simultaneously with the initiation of the process for hazard identification to allow a full recognition of the diverse issues that need to be addressed in the development process

2) Risk communication should be an open, inclusive and transparent process for which the strategy should be developed as the procedures for hazard identification of a particular case evolves.

3) Risk communications should be delivered in a format that addresses the needs of the audience for their decision making processes

4) Risk communication methodology must assure that all results of the risk analysis procedure are communicated in a format that is clear and useful to individuals and organizations who use the information in their own decision making process.

5) Risk communication methods should be carefully selected in light of the type of stakeholders involved and the target population to be addressed, thereby fostering a effective support

Risk communication may involve a step by step approach to issue for which uncertainty levels are different.

Annex 5: Sustainability Indicators and Characteristics

Adapted from pages 3-9 of the DFO report "Fuzzy Logic Modelling of Traffic Light Indicators" by William Silvert, 2001.

Introduction

There is a clear need to simplify and clarify the information used in environmental management. The data available are so voluminous and in some cases so esoteric that it is not possible to assimilate and analyse them effectively, especially given the time constraints that many managers and stakeholders face. Furthermore, coastal zone issues such as aquaculture concern different groups of people with different backgrounds and various levels of scientific sophistication. These issues all add to the difficulty of determining whether an activity is sustainable, even in a narrow biological sense. When we add concern for social and economic sustainability it is clear that the structure of the data and how it is analysed is of critical importance. This annex addresses some issues related to the definition of Sustainability Indicators and the broader concept of Characteristics which can be used to identify sustainable activities.

Information Flow in Environmental Management

Environmental management science can be thought of as a sort of "black box" for processing information, where the inputs are masses of biological, environmental and economic data, and the output is advice to management, including identification of those levels of activity which are sustainable. The workings of the black box are extremely complicated, and to make matters worse, it constantly being redesigned. There is a need to formalise the design of the process to make it more efficient, transparent and flexible. The first step in doing this is to find a way to describe the inner workings in a simplified modular way.

The crudest representation of the process is shown in Figure 1, showing the flow of information from raw data through the advisory process.

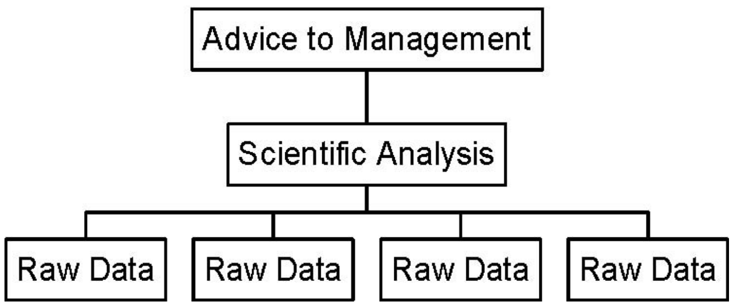

Figure 1. The "black box" picture of environmental management science

Problems with raw data, including changes in sampling protocols and incomplete results, are dealt with by scientists who try to provide results to management in a standard and easily comprehended form. In practice however the quantity of raw data is usually overwhelming and the process of scientific analysis gets broken into two parts, as shown in Figure 2:

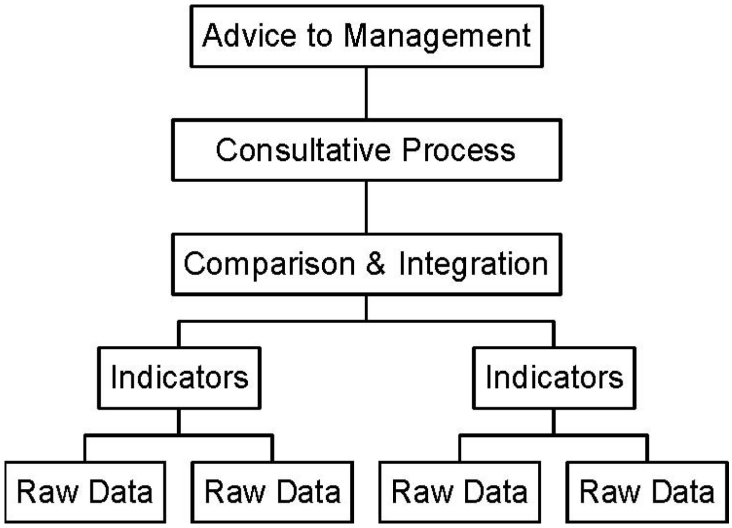

Figure 2. A "black box" picture of environmental management with a distinction between raw data and Indicators as input

Here the process of scientific analysis has been broken into two parts; first the assimilation and interpretation of raw data to provide meaningful Indicators of the quantities that the data measure, and second the comparison and integration of these Indicators to understand their implications for environmental management. The output of this analysis provides the input to the consultative process which addresses the issue of sustainability and provides advice to management.

The output of the scientific analysis of the data, the Comparison & Integration phase, is a set of quantitative values which are not really Indicators, since they involve a degree of abstraction and modelling of the inputs, and sometimes these are called Combined Indicators. An alternative term which is commonly used is Characteristics, which is what they will be called here.

The scheme shown in Figure 2 may in some cases be too detailed, as it is designed to be comprehensive. Sometimes a single raw datum need no processing and serves as an Indicator, and the meanings of some Indicators are clear enough to be passed through to the Consultative Process without any need for "Comparison and Integration". For generality we acknowledge in these cases that an Indicator can also be a Characteristic.

The distinction between Indicators and Characteristics is not always clear, and as just pointed out they may even be the same. Generally we use the term Indicator to refer to a measurable quantity, but since it may be the result of combining several different kinds of measurement it is not necessarily a raw datum. We use the word Characteristic for a derived quantity that cannot be directly measured. Thus we may consider biomass to be an Indicator since it could in principle be measured, even though we usually calculate it by estimating the number of fish in a pen and multiplying this number by the mean weight of the fish, but there is no direct way of measuring Feed Conversion Ratio so it is a Characteristic. Another example of an important Characteristic is the equilibrium level of nutrients in the water column, which can be calculated by the model

$$dC/dt = N - C/T$$

where C is the concentration, N is the rate of nutrient production, and T is the turnover time for the water body. The equilibrium level of C is obtained by setting $dC/dt=0$ and turns out to be NT, which is a useful Characteristic.

An additional point to emphasise is that not all aspects of sustainability can be represented by a set of indicators. One of the most important aspects of sustainability is reversibility, which ensures that even if we do some harm we can, in time, return to our starting point. Irreversible changes, such as extinction, represent a definite refutation of any claim of sustainability. We need to beware the tendency to focus on those things we can measure and ignore the larger issues that express themselves only in qualitative terms.

A Fisheries Example of Hierarchical Structure

The schema shown in Figure 1 and Figure 2 is basically hierarchical in structure. A concrete example is shown in Figure 3, which is just an excerpt from a hypothetical but realistic schema for managing fish stocks (taken from the DFO report).

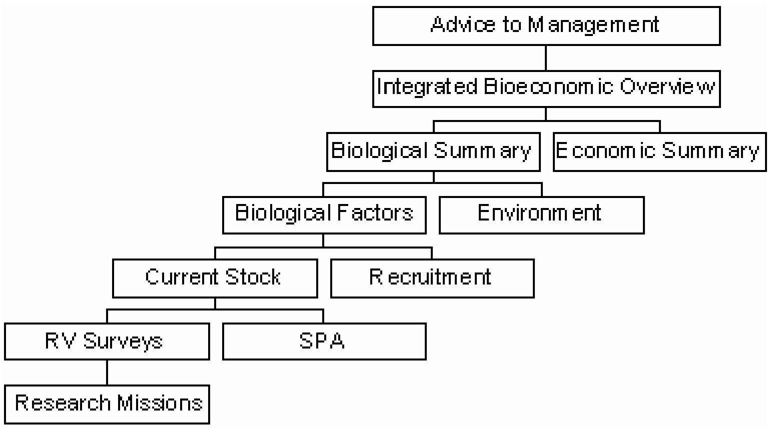

Figure 3. Section of a hierarchical system for fisheries management

The lowest level represents the raw data input to an RV survey, and the output of the survey itself is a biomass estimate which can be considered an Indicator (more rigorously we should probably speak of the actual catch data as Indicators, and the biomass estimate as a Characteristic). This can be evaluated in conjunction with another Indicator, the SPA estimate of biomass, to arrive at an estimate of the current stock size. This estimate is better thought of as a Characteristic, and the information represented by the Characteristics is the working material for the assessment process.

An estimator of stock size in conjunction with additional biological information on production and recruitment (i.e., other Characteristics), enables us to summarise the biological factors. These in turn are integrated with another set of Characteristics describing environmental factors to arrive at a summary characterising the biological status of the stock. Thus the Characteristics represent intermediate stages where the huge masses of input data are collated and condensed into useful measures of how the system is functioning, and in some cases they can also be used as performance measures to see how well management objectives are being achieved – this is primarily true of biological Characteristics like stock size, which indicate how well conservation policies are working, and less true of Characteristics which describe environmental factors not subject to management control.

It is hard to envision a situation where a single set of measurements, namely one or more Indicators, would be sufficient to determine the sustainability of an aquaculture site. Sustainability is a complex concept and would fall high on the hierarchical scale shown in Figure 3, representing the synthesis of a number of different Characteristics.

In some earlier work the picture drawn of the scientific process was simpler than that shown in Figure 3, with one layer of Indicators leading to one layer of Characteristics, and an Integrated Summary on top of that. However, this example shows that there may be several layers of Characteristics, and that what may look like a Summary to one group of scientists (in this case the Biological Summary) may simply be input to a higher level of integration as seen by another group; in this case the Biological Summary needs to be combined with the Economic

Summary to give an integrated bioeconomic overview that is the basis for advice to management.

The hierarchical model shown in Figure 3 is an idealised example, and it is seldom possible to describe the evaluation process in such a well-structured way. Some Indicator variables only feed into the next level of Characteristics – for example, temperature is an important environmental factor, but its key role is in determining the metabolic rates and growth of fish as well as affecting some geochemical processes. It is not the kind of variable that managers need to be concerned with, unless it reaches extreme values. Fish growth rate is a complex Characteristic which depends on temperature, nutrition, oxygen levels and many other Indicator variables.

How do Characteristics Depend on Indicators?

Each Characteristic is a node in the network that integrates the inputs from Indicators and other Characteristics. In general this process can be quite complex. At least three basic situations need to be considered (for brevity the inputs are referred to as Indicators, although some may be Characteristics):

- In the simplest case the Characteristic scales monotonically with the Indicator, so that the higher the Indicator value, the better (or worse) the status of the property that it represents, and the better (or worse) the prognosis. These Indicators can be referred to as "linear", since although the term is not strictly applicable in a mathematical sense, it is more familiar and clearer than the technical term "monotonic". For linear Indicators it may be possible to use statistical tools to assign cut points or other objective determinants of the traffic lights, but this is not necessarily the best approach.
- Many Indicators are non-linear, in the sense that there is range of values which is optimal, and values which are too high or too low are not. Temperature is clearly a non-linear Indicator, as are many other environmental variables.
- There are also some Indicators that are important but must be considered in conjunction with other Indicators to be meaningful. A fisheries example provided by Ram Myers (pers. comm.) is age structure as an Indicator. Predominance of small fish in the wild can indicate either strong recruitment or over-fishing of large fish. Taken by itself the variable cannot be interpreted, but in conjunction with other data, such as fishing effort, it provides valuable and meaningful information.

The distinction between linear and non-linear Indicators is not a major issue, and it is raised here only to show that attempts to assign values to Indicators on the basis of statistical properties of time series may be misguided. Indicators that are only meaningful when analysed in conjunction with other Indicators are called "incomplete", since they are not sufficient to provide useful information taken alone, but in conjunction with other Indicators they are of value. It is important to understand this distinction, since it is often believed that Indicators are intrinsically informative by themselves.

The price of fish is an example of an incomplete Indicator, since although it is obviously an important variable, it is impossible to assign value to it without taking into account additional variables such as supply, demand, and operational costs.

Condition is another example of an incomplete Indicator, since poor condition may be either the result of unfavourable environmental conditions or a consequence of poor husbandry. The correct interpretation is crucial for management decision-making, since if the fish are suffering from poor environmental conditions some fairly drastic action might be called for, such as moving fish pens, but their condition is caused by poor husbandry then the operator needs to learn better procedures.

It is not always clear whether an Indicator is complete, and it appears that some Indicators are prone to misinterpretation because of an eagerness to interpret incomplete Indicators as complete. For example, Indicators are often used as indices of social change, and one common Indicator is the percentage of women in various sectors of the labour force. In some countries the fraction of women in certain scientific fields is much higher than in Canada, which seems very progressive, except that it turns out in many cases that those fields are so poorly paid that they are condescendingly thought of as women's work. Thus treating a high employment rate for women as desirable may be misleading if the real reason is that men have preferential access to more highly paid jobs, and the situation is not one conducive to a sustainable society by contemporary western standards.

Defining and Redefining Indicators

Fortunately the definition of Indicators is fairly flexible, and by selecting the appropriate definitions it is possible to use mainly complete ones. For example, the number of fish in a pen and the mean weight are both possible Indicators, but if we multiply the number by the mean weight we get the biomass, which can be treated as a complete Indicator. On the other hand, some of the other Indicators that could be constructed from these data are incomplete since they are difficult to interpret without additional information. The example provided by Ram Myers (pers. comm.) mentioned above is that predominance of small fish in a wild fish population can indicate either strong recruitment or over-fishing of large fish. By itself the fraction of small fish in the population cannot be interpreted meaningfully, but in conjunction with other data, such as fishing effort, it becomes useful. Similarly, the net revenue from the fishery is relatively complete in comparison to related Indicators such as the price of fish, total biomass, and employee salaries. It is clearly important to select the Indicators appropriately so that as many of them as possible are complete.

While it is quite simple to see that biomass is a better Indicator from this point of view than either numbers or mean weight, identification of the best Indicators is not always trivial. For example, consider the predatory impact of seals on wild fish populations. Both numbers and biomass of seals could be considered reasonable Indicators, but Brodie (1984) has pointed out that metabolic demand scales allometrically as approximately the inverse cube root of the weight, so that the demand for food should be the number of seals times the mean value of weight to the 2/3 power, which turns out to be the total surface area of the seal population! This is probably one of the odder Indicators that has been proposed for environmental management, but it illustrates the point that selection of the right Indicators is an important part of the process.

Not all Indicators can be expressed in a complete form in the context of a hierarchical management scheme. The cod glut of the 1970's occurred at a time when all the biological Indicators were highly favourable and the fish landings were so great that the market could not absorb the supply, and prices plummeted; the same can occur with farmed fish. It is only when production data are integrated with economic data on the elasticity of demand, which of course occurs at the highest levels of the hierarchy, that the real impact on the industry is apparent.

Indicators of Social Sustainability

While the social sciences lie outside the competence of the current WGEIM membership, some extensions of the above biological examples may be informative. For example, consider the level of employment in the aquaculture industry, which is clearly an important socioeconomic Indicator. Taken by itself it is not a comprehensive measure of the social sustainability of the industry, since the viability of local communities depends on whether there are enough jobs to maintain social cohesion and justify the kind of infrastructure (such as road maintenance) that the aquaculture industry needs. In many cases aquaculture has been developed as an alternative industry for fishermen displaced from the wild fishery, but this sometimes involves a reduction in the total work force; if fishermen who cannot find alternate employment move away, the community might collapse (stores and schools closing, etc.) and even though the total income may remain as high, the social situation may not prove sustainable. This pattern has been seen repeatedly in agriculture where in many cases small farms go out of business not because they are fundamentally unprofitable, but because the farming communities have collapsed and there is no place to buy supplies, no schools for their children, and no transportation facilities to move their produce to market. On the other hand, the introduction of aquaculture has sometimes greatly improved the local job market and has led to population growth and enhanced infrastructure. Thus the number of jobs created by aquaculture is only an incomplete Indicator and is only useful when considered in an appropriate context.

A very simple example of how Indicators by themselves are not meaningful until combined into Characteristics is the simple economic formula,

$$Profit = Price \times Production - Cost$$

since none of these three Indicators is meaningful by themselves; compare carp production in China (low Price, high Production, low Cost) with sturgeon farming (high Price, low Production, high Cost).

Problems of Scale

In dealing with issues of sustainability we need to ask what scale we are considering. There is a great deal of concern about the use of wild fish to feed farmed carnivores, but relatively little discussion of where the wild fish come from, and in what quantity. Because of the high worldwide production of salmon this is one of the types of aquaculture that has received the greatest scrutiny, but perhaps we should compare the sustainability of the prey populations eaten by wild salmon on their migration routes and that of the Peruvian anchovetas which constitute the world's largest source of fish meal. We should perhaps also ask to what extent we should seek to control the use of wild fish products for the production of small-scale high-value carnivorous fish. Although the percentage of wild fish products in the diet is an important Indicator of sustainability on a global scale, this needs to be combined with information on quantity and type of fish to be meaningful.

Time scales are also a factor. No matter how carefully we manage the aquaculture industry there will be fluctuations and some Indicators are bound to waver into the zone of nonsustainability. How long a period of poor conditions we are able to tolerate is a critical question. Nutrification leading to harmful algal blooms is clearly undesirable, but generally the effects are not long lasting (massive blooms that settle out and cause anoxia on the seabed are an exception to this). The benthic impacts of carbon loading on the other hand can persist for years, but since there may be recovery in the long term even these effects may be considered sustainable. Irreversible changes such as changes of the gene pool of wild stocks due to interbreeding with escapees are clearly not sustainable, even though on truly long time scales these effects may be erased by evolutionary changes. While sustainability means that the system is able to recover when things go wrong, the time it takes to recover is a significant factor that is not easily defined.

Summary

While this discussion document does not claim to provide any definitive answer to the issues raised in the 2006 report, it has tried to elaborate on the role that Indicators can play and how they are incorporated into the decision-making process. Although some Indicators are intrinsically good measures of the state of the system, many require further analysis and are only meaningful when combined with other Indicators. The derivation of Characteristics represents part of this process, but even these more complex measures of system condition should be seen only as input to a process of evaluation, and it is not clear that the sustainability of a system can be determined simply by mathematical manipulation of measurable quantities. Even so, Indicators describing the current conditions can provide valuable input to the management process and can be interpreted in ways that make the performance of the industry more transparent to all stakeholders.

Annex 6: 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 predictions[1], 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 species[2]. However, warmer waters may provide opportunities to culture new species, or species that are currently economically marginal in Scotland[3].

Diseases of cultured fish and shellfish[4], including bacterial[5], viral[6], parasitic[7] and fungal[8] 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 interventions[7]. 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 algal[10] 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 areas[11]. 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 predicted 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 ºC by 2020 and up to 2.5 ºC 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 7ºC) [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 <6ºC) 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^{o}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^{o}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^{o}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 endngered 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 over-winter 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 over-wintering 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 difficuly 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.

[11]**Shellfish 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.

Bibliography

1. Reddin, D.G., P. Downton, and K.D. Friedland, *Diurnal and nocturnal temperatures for Atlantic salmon postsmolts (Salmo solar L.) during their early marine life.* Fishery Bulletin, 2006. **104**(3): p. 415-427.
2. Cano, J.M. and A.G. Nicieza, *Temperature, metabolic rate, and constraints on locomotor performance in ectotherm vertebrates.* Functional Ecology, 2006. **20**(3): p. 464-470.
3. Takle, H., A. McLeod, and O. Andersen, *Cloning and characterization of the executioner caspases 3, 6, 7 and Hsp70 in hyperthermic Atlantic salmon (Salmo salar) embryos.* Comparative Biochemistry And Physiology B-Biochemistry & Molecular Biology, 2006. **144**(2): p. 188-198.
4. Goniea, T.M., et al., *Behavioral thermoregulation and slowed migration by adult fall Chinook salmon in response to high Columbia River water temperatures.* Transactions Of The American Fisheries Society, 2006. **135**(2): p. 408-419.

5. Galbreath, P.F., et al., *Thermal tolerance of diploid versus triploid rainbow trout and brook trout assessed by time to chronic lethal maximum.* Environmental Biology Of Fishes, 2006. **75**(2): p. 183-193.
6. Larsson, S. and I. Berglund, *Thermal performance of juvenile Atlantic salmon (Salmo salar L.) of Baltic Sea origin.* Journal Of Thermal Biology, 2006. **31**(3): p. 243-246.
7. Levesque, H.M., et al., *Effects of seasonal temperature and photoperiod on Atlantic cod (Gadus morhua). II. Enzymes of intermediary metabolism.* Canadian Journal Of Fisheries And Aquatic Sciences, 2005. **62**(12): p. 2864-2873.
8. Claireaux, G., et al., *Physiology And Behavior Of Free-Swimming Atlantic Cod (Gadus-Morhua) Facing Fluctuating Temperature Conditions.* Journal Of Experimental Biology, 1995. **198**(1): p. 49-60.
9. Hurst, T.P., et al., *Compensatory growth, energy storage and behavior of juvenile Pacific halibut Hippoglossus stenolepis following thermally induced growth reduction.* Marine Ecology-Progress Series, 2005. **293**: p. 233-240.
10. Imsland, A.K., et al., *Intraspecific differences in physiological efficiency of Juvenile Atlantic halibut Hippoglossus hippoglossus L.* Journal Of The World Aquaculture Society, 2000. **31**(3): p. 285-296.
11. Aune, A., A.K. Imsland, and K. Pittman, *Growth of juvenile halibut, Hippoglossus hippoglossus (L.), under a constant and switched temperature regime.* Aquaculture Research, 1997. **28**(12): p. 931-939.
12. Bjornsson, B. and S.V. Tryggvadottir, *Effects of size on optimal temperature for growth and growth efficiency of immature Atlantic halibut (Hippoglossus hippoglossus L.).* Aquaculture, 1996. **142**(1-2): p. 33-42.
13. Duguid, J.P., B.P. Marmion, and R.H.A. Swain, *Medical Microbiology*. 13 ed. Vol. 1. 1978, Edinburgh, London and New York: Churchill Livingstone. 666.
14. Le Morvan, C., P. Deschaux, and D. Troutaud, *Effects and mechanisms of environmental temperature on carp (Cyprinus carpio) anti-DNP antibody response and non-specific cytotoxic cell activity: a kinetic study.* Dev Comp Immunol, 1996. **20**(5): p. 331-40.
15. Lillehaug, A., *Vaccination strategies in seawater cage culture of salmonids.* Dev Biol Stand, 1997. **90**: p. 401-8.
16. van Muiswinkel, W.B. and G.F. Wiegertjes, *Immune responses after injection vaccination of fish.* Dev Biol Stand, 1997. **90**: p. 55-7.
17. Eggset, G., H. Mikkelsen, and J.E.A. Killie, *Immunocompetence and duration of immunity against Vibrio salmonicida and Aeromonas salmonicida after vaccination of Atlantic salmon (Salmo salar L.) at low and high temperatures.* Fish & Shellfish Immunology, 1997. **7**(4): p. 247-260.
18. Benediktsdottir, E., et al., *Characterization of Vibrio viscosus and Vibrio wodanis isolated at different geographical locations: a proposal for reclassification of Vibrio viscosus as Moritella viscosa comb. nov.* International Journal Of Systematic And Evolutionary Microbiology, 2000. **50**: p. 479-488.
19. Coyne, R., et al., *Winter ulcer disease of post-smolt Atlantic salmon: An unsuitable case for treatment?* Aquaculture, 2006. **253**(1-4): p. 171-178.
20. Nordmo, R. and A. Ramstad, *Variables affecting the challenge pressure of Aeromonas salmonicida and Vibrio salmonicida in Atlantic salmon (Salmo salar L.).* Aquaculture, 1999. **171**(1-2): p. 1-12.
21. Nordmo, R., S. Sevatdal, and A. Ramstad, *Experimental infection with Vibrio salmonicida in Atlantic salmon (Salmo salar L.): an evaluation of three different challenge methods.* Aquaculture, 1997. **158**(1-2): p. 23-32.
22. Steine, N.O., G.O. Melingen, and H.I. Wergeland, *Antibodies against Vibrio salmonicida lipopolysaccharide (LPS) and whole bacteria in sera from Atlantic salmon (Salmo salar L.) vaccinated during the smolting and early post-smolt period.* Fish & Shellfish Immunology, 2001. **11**(1): p. 39-52.
23. Lillehaug, A., B.T. Lunestad, and K. Grave, *Epidemiology of bacterial diseases in Norwegian aquaculture - a description based on antibiotic prescription data for the ten-year period 1991 to 2000.* Diseases Of Aquatic Organisms, 2003. **53**(2): p. 115-125.
24. Eggset, G., et al., *Susceptibility to furunculosis, cold water vibriosis, and infectious pancreatic necrosis (IPN) in post-smolt Atlantic salmon (Salmo salar L.) as a*

function of smolt status by seawater transfer. Aquaculture, 1997. **158**(3-4): p. 179-191.

25. Rose, A.S., A.E. Ellis, and A.L.S. Munro, *The infectivity by different routes of exposure and shedding rates of Aeromonas salmonicida subsp. salmonicida in Atlantic salmon, Salmo salar L., held in sea water.* J. Fish Dis, 1989. **12**(6): p. 573-578.
26. Roberts, R.J., *Bacterial diseases of farmed fishes.* Soc Appl Bacteriol Symp Ser, 1976. **4**: p. 55-62.
27. Hirvela-Koski, V., et al., *Atypical growth of Renibacterium salmoninarum in subclinical infections.* Journal Of Fish Diseases, 2006. **29**(1): p. 21-29.
28. Bruno, D.W., *Prevalence and diagnosis of bacterial kidney disease (BKD) in Scotland between 1990 and 2002.* Diseases Of Aquatic Organisms, 2004. **59**(2): p. 125-130.
29. Jacobson, K.C., et al., *Cumulative effects of natural and anthropogenic stress on immune function and disease resistance in juvenile chinook salmon.* Journal Of Aquatic Animal Health, 2003. **15**(1): p. 1-12.
30. Nagai, T. and Y. Iida, *Occurrence of bacterial kidney disease in cultured ayu.* Fish Pathology, 2002. **37**(2): p. 77-81.
31. Piganelli, J.D., G.D. Wiens, and S.L. Kaattari, *Elevated temperature treatment as a novel method for decreasing p57 on the cell surface of Renibacterium salmoninarum.* Diseases Of Aquatic Organisms, 1999. **36**(1): p. 29-35.
32. Jonsdottir, H., et al., *Epidemiology of Renibacterium salmoninarum in wild Arctic charr and brown trout in Iceland.* Journal Of Fish Biology, 1998. **53**(2): p. 322-339.
33. Bond, C.E., *The Biology of Fishes*. **1996**, New York: **Thomson Learning**. 576.
34. Bricknell, I.R., J.E. Bron, and T.J. Bowden, *Diseases of gadoid fish in cultivation: a review.* Ices Journal Of Marine Science, 2006. **63**(2): p. 253-266.
35. Skall, H.F., N.J. Olesen, and S. Mellergaard, *Prevalence of viral haemorrhagic septicaemia virus in Danish marine fishes and its occurrence in new host species.* Diseases Of Aquatic Organisms, 2005. **66**(2): p. 145-151.
36. Skall, H.F., N.J. Olesen, and S. Mellergaard, *Viral haemorrhagic septicaemia virus in marine fish and its implications for fish farming - a review.* Journal Of Fish Diseases, 2005. **28**(9): p. 509-529.
37. Einer-jensen, K., et al., *Evolution of the fish rhabdovirus viral haemorrhagic septicaemia virus.* Journal Of General Virology, 2004. **85**: p. 1167-1179.
38. Bowden, T.J., *A study of the susceptibility of Atlantic halibut, Hippoglossus hippoglossus (L.), to viral haemorrhagic septicaemia virus isolated from turbot, Scophthalmus maximus (L.).* Journal Of Fish Diseases, 2003. **26**(4): p. 207-212.
39. Park, K.C. and P.W. Reno, *Molecular size, pH, temperature stability, and ontogeny of inhibitor(s) of infectious pancreatic necrosis virus (IPNV) in normal rainbow trout serum.* Journal Of Aquatic Animal Health, 2005. **17**(2): p. 177-190.
40. Bowden, T.J., D.A. Smail, and A.E. Ellis, *Development of a reproducible infectious pancreatic necrosis virus challenge model for Atlantic salmon, Salmo salar L.* Journal Of Fish Diseases, 2002. **25**(9): p. 555-563.
41. Kollner, B., et al., *Evaluation of immune functions of rainbow trout (Oncorhynchus mykiss) - how can environmental influences be detected?* Toxicology Letters, 2002. **131**(1-2): p. 83-95.
42. Jarp, J., T. Taksdal, and B. Torud, *Infectious pancreatic necrosis in Atlantic salmon Salmo salar in relation to specific antibodies, smoltification, and infection with erythrocytic inclusion body syndrome (EIBS).* Diseases Of Aquatic Organisms, 1996. **27**(2): p. 81-88.
43. Stangeland, K., S. Hoie, and T. Taksdal, *Experimental induction of infectious pancreatic necrosis in Atlantic salmon, Salmo salar L, post-smolts.* Journal Of Fish Diseases, 1996. **19**(4): p. 323-327.
44. Drinkwater, K.F., *The response of Atlantic cod (Gadus morhua) to future climate change.* Ices Journal Of Marine Science, 2005. **62**(7): p. 1327-1337.
45. Rose, G.A., *On distributional responses of North Atlantic fish to climate change.* Ices Journal Of Marine Science, 2005. **62**(7): p. 1360-1374.
46. Clark, R.A., et al., *North Sea cod and climate change - modelling the effects of temperature on population dynamics.* Global Change Biology, 2003. **9**(11): p. 1669-1680.

47. Boxaspen, K., *Geographical and temporal variation in abundance of salmon lice (Lepeophtheirus salmonis) on salmon (Salmo salar L.).* ICES Journal of Marine Science, 1997. **54**(6): p. 1144-1147.
48. Boxaspen, K. and T. Naess, *Development of eggs and the planktonic stages of salmon lice (Lepeophtheirus salmonis) at low temperatures.* Contributions to Zoology, 2000. **69**(1-2): p. 51-55.
49. Heuch, P.A., A. Parsons, and K. Boxaspen, *Diel vertical migration: a possible host-finding mechanism in salmon louse (Lepeophtheirus salmonis) copepodids?* Canadian Journal of Fisheries and Aquatic Sciences, 1995. **52**(4): p. 681-689.
50. Johnson, S.C. and L.J. Albright, *The developmental stages of Lepeophtheirus salmonis (Krøyer, 1837) (Copepoda, Caligidae).* Canadian Journal of Zoology, 1991. **69**(4): p. 929-950.
51. Johnson, S.C. and L.J. Albright, *Development, growth, and survival of Lepeophtheirus salmonis (Copepoda, Caligidae) under laboratory conditions.* Journal of the Marine Biological Association of the United Kingdom, 1991. **71**(2): p. 425-436.
52. Pike, A.W. and S. Wadsworth, *Sealice on salmonids: their biology and control.* Advances in Parasitology, 2000. **44**: p. 233-337.
53. Gieseker, C.M., S.G. Serfling, and R. Reimschuessel, *Formalin treatment to reduce mortality associated with Saprolegnia parasitica in rainbow trout, Oncorhynchus mykiss.* Aquaculture, 2006. **253**(1-4): p. 120-129.
54. Udomkusonsri, P. and E.J. Noga, *The acute ulceration response (AUR): A potentially widespread and serious cause of skin infection in fish.* Aquaculture, 2005. **246**(1-4): p. 63-77.
55. Lategan, M.J., F.R. Torpy, and L.F. Gibson, *Control of saprolegniosis in the eel Anguilla australis Richardson, by Aeromonas media strain A199.* Aquaculture, 2004. **240**(1-4): p. 19-27.
56. de Canales, M.L.G., et al., *Saprolegniasis in wild fish populations.* Ciencias Marinas, 2001. **27**(1): p. 125-137.
57. Howe, G.E. and G.R. Stehly, *Experimental infection of rainbow trout with Saprolegnia parasitica.* Journal Of Aquatic Animal Health, 1998. **10**(4): p. 397-404.
58. Howe, G.E., J.J. Rach, and J.J. Olson, *Method for inducing saprolegniasis in channel catfish.* Journal Of Aquatic Animal Health, 1998. **10**(1): p. 62-68.
59. Quiniou, S.M.A., et al., *Effects of water temperature on mucous cell distribution in channel catfish epidermis: a factor in winter saprolegniasis.* Fish & Shellfish Immunology, 1998. **8**(1): p. 1-11.
60. Neat, F. and Righton D. *Warm water occupancy by North Sea cod*. Proc. Roy. Soc. B., 2006. Submitted.
61. Edwards, M., Johns D.G., Leterme S.C., Svendsen E. and Richardson A.J. *Regional climate change and harmful algal blooms in the NE Atlantic*. Limnol. Oceanogr. 2006. **51**(2), 820-829.
62. Edwards, M. and Richardson A.J. *Impact of climate change on marine pelagic phenology and trophic mismatch.* Nature, 2004. **430**, 881-884.
63. Wasmund, N, Nausch, G. and Matthaus, W. *Phytoplankton spring blooms in the Southern North Sea. Spatio-temporal development and long term trends.* J. Plankton Res., 1998. **20** 1099-1117.
64. Saetre, R., Aure, J. and Danielssen, D.S. *Long-term hydrographic variability patterns off the Norwegian coast and in the Skagerrak*. ICES Mar. Sci. Symp., 2003. **219**, 150-159.

Annex 7: Draft WGEIM terms of reference for the next meeting

The ToRs listed below are tentative in nature due to concern over workload at meetings. ToRs a-c will be dealt with as they build on previous years. ToR g will occur given the location. The working group members will be asked to prioritise the terms of reference and this information will be presented to the Mariculture Committee at the Annual Science Conference in September 2008. Decision will then be taken regarding the work programme of WGEIM for 2008 and beyond.

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 fora.

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) assess the potential impact of climate change on aquaculture activities relevant to each ICES member state.

e) review the use of seed stock quality criteria in mariculture and their applications in term of ecological performance.

f) review impact indices for mariculture activities with a view to comparing and resolving them those utilised to measure conservation status/goals and conclusions derived on their utility and recommendation provided on potential indices that may be utilised and easily applied by regulators of both sectors.

g) conduct a joint session with PICES and/or WGMASC whereby subjects of mutual interest will be discussed.

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	**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 modeling 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 **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 epifuanal 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 acitivity. This ToR will highlight existing examples and will

	address the management implications and potential mitigation strategies. Lead: Chris McKindsey, Canada **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 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: Steven Cross, Canada d) 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, Aberdeen4 (Annex 6) 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. Lead: No lead assigned yet e) 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: No lead assigned yetf) The management of environmental impacts from mariculture can be based on policies that are difficult to interpret particularly as they relate to interactions with conservation driven objectives. 'No net loss', 'habitat replacement' and maintenance of 'good conservation status' are some of the terms used to govern management of traditional and mariculture activities in both North America and Europe. The ambiguity attached to these management objectives lead to confusion and has been described as an impediment to aquaculture development. Lead: No lead assigned yet The upshot of all these situations and scenarios is that there is considerable confusion regarding the impact conservation goals might have on the management of mariculture activities and the potential for conflict of legislation is high. It would appear that a review of national policies and indices used to measure sustainability of mariculture (ToR B) should also include as a driver, i.e., legislative constraints, particularly those imposed by conservation related policies. From a more practical perspective the development of indices and subsequent setting of standards that have relevance to both the conservation objectives and mariculture management strategies, would seem to be an important end point. Lead: No lead assigned yetg) The next meeting is proposed for British Columbia thus presenting an opportunity to liaise with PICES.
Resource Requirements	None

4 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

Participants	The Group is normally attended by some 12–15 members and guests
Secretariat Facilities	None
Financial	No financial implications
Linkages to Advisory Committees	ACME
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 8: Actions and Recommendations

Recommendations		Action
1	**Recommendation:** Sustainability Indices are more comprehensive than environmental impacts assessments. They incorporate and try to integrate the “triple bottom line” concept (social, economic, and environmental) assessments. We recognize that the strength of ICES is in the environmental and ecological fields, but to develop SIs further, ICES needs to broaden the scope of investigations to incorporate social and economic assessments as highlighted in the Action Plan No. 3.12. This experience should be brought to WGEIM to deal with this ToR specifically. In the absence of such experience this will result in only an incomplete conclusions by the group of this subject area.	ICES/MARC
3	**Recommendation:** WGEIM recommends that a review of existing Integrated Multi-Trophic Aquaculture IMTA programs and specific projects continues as a Term of Reference for WGEIM 2008.	MARC/ICES
4	**Recommendation:** 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.	WGEIM/MARC
5	**Recommendation:** The WGEIM recommends that the introduction of new species and husbandry techniques to mariculture should all include a practical and appropriate risk assessment of the environmental risks and interactions.	ICES/WGEIM
6	**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
7	**Recommendation:** WGEIM recommends that given the global importance of mariculture, it is important that ICES continue to include mariculture as a primary focus in future action plans.	ICES
8	**Recommendation:** WGEIM recommends that it broaden it 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
9	**Recommendation:** WGEIM recommend that Drs. Francis O’Beirn and Chris McKindsey be appointed co-chairs of WGEIM for 2008	MARC/ICES
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:** WGEIM agreed that members of the working group finish a review manuscript of alternate feeds in maricultures intercessionally and submit it for publication in a peer reviewed scientific journal.	WGEIM
3	**Action:** Members of WGEIM agreed to gather information relating to aquaculture interactions and proposed indicators intersessionally to explore the usefulness and interpretability of the proposed indices, and to present this information at WGEIM 2008.	
4	**Action:** WGEIM Chair to canvass members by presenting a list of proposed Terms of reference for the working group and asking them to prioritise them in terms of importance and also identify what role they would take in progressing the ToR.	WGEIM

5	**Action:** WGEIM Chair to canvass members on prospective contributors to the WGEIM/WGMASC Joint theme Session on Ecological Carrying capacity. In addition, member's view on the specific terms of reference for the session will be solicited in order that a clearly defined invitation can be proffered.	WGEIM/WGMASC