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Report of the Working Group on Environmental Interactions of Mariculture (WGEIM)

11–15 April 2005

Ottawa, Canada

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Conseil International pour l'Exploration de la Mer

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Executive Summary

The Working Group on the Environmental Interactions of Mariculture (WGEIM) met at the Department of Fisheries and Oceans, in Ottawa, Canada from 11–15 April 2005. This year's meeting was attended by 13 scientists from 8 countries, including an observer from the Canadian Aquaculture industry.

Five Terms of Reference were addressed by the group. The first two covered much the same subject matter and specifically dealt with the development of risk analysis of escaped non-salmonid aquacuture fish species. During the meeting, members of WGEIM continued to elaborate on documents describing the fundamental aspects of Risk Analysis, and applying the procedure to environmental interactions of aquaculture. Specifically, work was done on: (1) Improving the logical links between the expression of the theoretical aspects of Risk Analysis and its application to environmental aspects of aquaculture, (2) developing examples of Logic Models to aid the consequence analysis stage of the process, (3) clarifying criteria used in decision matrices and (4) specifically applying the risk analysis to turbot. These documents and those of the other species dealt with by WGEIM 2004 will be finalised intersessionally, following review by WGAGFM, the Mariculture Committee and the GESAMP WG-31. These actions will form the basis of a term of reference for WGEIM 2006.

The implementation of the Water Framework Directive in European Union member states**.** During 2004 a review of the impact of human activities on the status of surface waters and on groundwater was produced. Mariculture was considered a pressure acting on a waterbody and was incorporated into the pressures and impacts analysis in some Member States. Examples were presented of how mariculture as a risk was dealt with in two countries (Ireland and Scotland). In Ireland, bottom culture of mussels, because of its extensive nature was considered a risk that might impact on the physical structure of the waterbody and was therefore considered to present a pressure under morphological assessment. Lack of information pertaining to the broader scale impacts of finfish and other shellfish culture techniques resulted in all water bodies having licensed aquaculture activities (shellfish and finfish) being classed as 'probably not at risk'. In Scotland, it was recognised that the intensity of fish farm activity varies between water bodies (sea lochs). The most highly utilised lochs were assigned as 'probably at risk'. Moderately used lochs were assigned as 'probably not at risk', and relatively low intensity lochs were assigned as 'not at risk'. The EU Marine Strategy proposes to extend beyond the limits of the WFD. Aquaculture expansion into more open waters may be impacted by this initiative. It is important that the group (and ICES) be aware of the developments in relation to this legislation, therefore WGEIM recommends the potential impacts of current and new EU legislation on Mariculture activities should continue to be assessed by the group.

Models and tools for assessing the carrying capacity of an area of interest for shellfish culture can be classified according to their level of complexity and scope. WGEIM discussed and outlined four hierarchical categories of carrying capacity studies (i.e., *physical*, *production*, *ecological*, and *social carrying capacity).* To date, the majority of carrying capacity estimation has focused upon defining production limits. Assessing the ecological carrying capacity of a system has proven to be challenging and has received little attention from scientists and managers alike. To progress the issue, the WGEIM recommends that future modelling efforts should focus on the following issues as they relate to *ecological carrying capacity* studies (1) studies must be done to better understand the role of various types of bivalve culture installations (and other steps in bivalve aquaculture) in the environment, with a balanced emphasis on both "negative" and "positive" influences, (2) existing models must be made spatially explicit, (3) temporal variation must be built into existing models, and (4) models must be validated in a number of locations to evaluate their generality.

Sustainability Indices (SIs) are useful to resource managers who must process large amounts of scientific information and make numerous environmental decisions. Sustainability indexes may offer a methodology for monitoring or prioritizing those systems most in need of immediate management attention, and would allow scarce management assets to be applied in the most cost-effective manner. An EU FP6 project is currently under way with the stated goal of reviewing and recommending the best indicators for aquaculture activities. WGEIM will continue to monitor the progress of this project and others in light of a number of criteria regarding the usefulness of sustainability indicators for aquaculture. WGEIM emphasize that SIs must have high scientific credibility, be flexible and adaptive, as well as sustainable (e.g., cost-effective).

The principles of ecological aquaculture are that it treats and recycles its own wastes to mitigate cumulative environmental effects. An approach to mitigate the environmental impacts is by integrating fed aquaculture (finfish, shrimp) with inorganic and organic extractive aquaculture (seaweed, shellfish) whereby the wastes from one resource user becomes a resource (fertilizer, food) for the other. The terminology that is used interchangeably to refer to this form of mariculture includes, polyculture, integrated, aquaculture, multi-trophic aquaculture (MTA), ecological aquaculture and sustainable aquaculture. The advantages of MTA are: reduction in net effluent discharges; shared operational resources is more cost-effective; production intensification without environmental degradation; diversification of production-market potential, sustainable approach to aquaculture results in public awareness benefits; development of aquaculture in remote coastal communities; and improvement to overall water quality may reduce likelihood of disease outbreaks. The disadvantages are: a technically more complex operation with higher total capital costs; a greater scope of technical expertise is required; handling (e.g., grading, harvesting) of individual species components is more difficult; monitoring & control of disease organisms is more difficult; can require extensive areas for development; maintaining optimal environmental conditions (e.g., temperature, salinity) for multiple species; water quality effects among integrated components may require management (e.g., sea food safety). There are many technical details of integrated mariculture that need to be addressed through further research focusing upon pond-based (closed) and intensive and extensive coastal (open) systems. However, to successfully transfer the concept of integrated aquaculture to industry the technical challenges associated with the practical aspects (cost-effectiveness) of commercial-scale facilities must be addressed. Future challenges should consider pilot-scale testing of integrated aquaculture systems to permit these issues to be addressed accordingly.

1 Opening of the meeting

Dr Francis O'Beirn (Chair) opened the 2005 meeting of the Working Group on the Environmental Interactions of Mariculture (WGEIM) at the Department of Fisheries and Oceans, in Ottawa, Canada. This year's meeting was attended by 13 scientists from 8 countries, including an observer from the Canadian Aquaculture industry (see Annex 1). The membership constituted a range of expertise able to cover all terms of reference for this meeting.

The group was welcomed to the DFO by Dr Joan Kean-Howie, Director General for Aquaculture Science who expressed the delight of DFO in having the group in Canada (the first time in 18 years that the group has met in North America). Dr Kean-Howie, reiterated DFO commitment and support for ICES and its goals and ideals. The Chair, on behalf of the group, expressed considerable gratitude to the local host, Dr Edward Black, for the preparations and facilities for the meeting.

In the intersessional period it was noted that a paper prepared under the auspices of the WGEIM entitled:

A review and assessment of environmental risk of chemicals used for the treatment of sea lice infestations of cultured salmon, by K. Haya*, L. E. Burridge, I. M. Davies* and A. Ervik* was accepted for publication 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.

Congratulations were proffered to the authors on the publication of this important contribution.

The working arrangements were described, whereby a series of sub-groups would be formed each to address a specific term of reference. A sub-group leader would be assigned, who would be responsible for compiling the contributions of the others within the group.

(* WGEIM Members)

2 Adoption of the Agenda

A draft agenda was circulated in advance the meeting and with minor modification was accepted by the group. The adopted agenda is presented in Annex 2.

3 Terms of Reference

The terms of reference for the group were presented to the members in advance of the meeting and are presented below.

a) prepare a publication on the "state of knowledge" of the potential impacts of escaped aquaculture marine (non-salmonid) finfish species on local native wild stocks and complete the risk analyses of escapes of non-salmonid farmed fish (cod, sea bass, sea bream, halibut, turbot);

b) work with GESAMP WG 31 to develop aquaculture risk analysis methodologies;

c) update the report on developments in implementation of WFD and EU Strategy for sustainable aquaculture;

d) evaluate the recent developments over the last 5 years in carrying capacity models for shellfish with a view to proposing an ICES theme session or co-sponsored symposium in this area;

e) consider and evaluate the possibility for developing a "sustainability index" concerning environmental interactions of mariculture;

f) 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.

WGEIM will report by 30 April 2005 for the attention of the Mariculture and Diadromous Fish Committees and ACME.

3.1 Term of Reference a and b: Prepare a publication on the "state of knowledge" of the potential impacts of escaped aquaculture marine (non-salmonid) finfish species on local native wild stocks and complete the risk analyses of escapes of non-salmonid farmed fish (cod, sea bass, sea bream, halibut, turbot) and work with GESAMP WG 31 to develop aquaculture risk analysis methodologies

GESAMP, the IMO/FAO/UNESCO-IOC/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection, has a global concern for aspects of marine environmental quality. During the 2001 Session of GESAMP, Working Group 31 on Environmental Impacts of Coastal Aquaculture was charged with the task of producing a review report and guidelines for risk assessment of coastal aquaculture, aimed at promoting harmonisation and consistency in the treatment of risk and uncertainty, and improved risk communication.

More specifically, Working Group 31 was requested to examine the whole issue of risk assessment and communication, with particular emphasis on the treatment of uncertainty, as it relates to coastal development, using primarily coastal aquaculture as a case study. The outputs of the study will comprise a review report and a set of guidelines for risk assessment of coastal aquaculture based upon this review. These will be targeted primarily at those undertaking environmental assessments and cost benefit analyses of coastal aquaculture development. They will seek to promote harmonisation and consistency in the treatment of risk and uncertainty, and improved risk communication.

During the formation of the GESAMP group to undertake this task, it became clear to FAO and ICES that there were parallels between the work of the ICES WGEIM and the task being addressed by GESAMP WG31. Therefore it had been agreed that ICES would be linked to the project through common membership of the Core Team of GESAMP WG31 and ICES WGEIM. The initial meeting of the Core Team was held in November 2003, and included three past chairs of WGEIM (E Black, H Rosenthal and I Davies).

Since the last meeting of WGEIM, a paper describing the progress of the work being undertaken variously through GESAMP WG31 and ICES WGEIM was presented in a paper to ICES ASC 2004 (I. M. Davies, U. Barg, and E. Black, GESAMP initiative on environmental risk analysis for coastal aquaculture, ICES CM 2004/V:05). The paper highlighted that Risk Analysis is already being used as a 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 working with ICES WGEIM to develop Risk Analysis methodologies for analyzing environmental risks associated with aquaculture activities. It is hoped that their application to the environmental risks associated with changes in the pattern of cultivation of marine species (introductions of new species to cultivation, expansions or changes in the pattern of exploitation of species already in cultivation, etc) will enable better science-based management of existing resources and allow a more complete and equitable integration of aquaculture into the existing mix of coastal resource use.

During the meeting, members of WGEIM continued to elaborate on documents describing the fundamental aspects of Risk Analysis (Annex 3), and also to consider applying the procedure to environmental interactions of aquaculture. Specifically, work was done on:

- Improving the logical links between the expression of the theoretical aspects of Risk Analysis and its application to environmental aspects of aquaculture;
- Developing examples of Logic Models to aid the consequence analysis stage of the process;
- Clarifying criteria used in decision matrices;
- Applying the risk analysis to turbot (Annex 4).

These documents will be finalised intersessionally, following review by WGAGFM, the Mariculture Committee and the aforementioned GESAMP group. This action will form the basis of a term of reference for WGEIM 2006.

3.2 Term of Reference c: Update the report on developments in implementation of WFD and EU Strategy for sustainable aquaculture

Implementation of the Water Framework Directive has progressed in EU member during 2004 with the publication of the Article V (Characterisation) report. The characterization report provides;

- An overview of River Basin District characteristics;
- A review of the impact of human activity on the status of surface waters and on groundwater; and
- An economic analysis of water use.

For all groundwaters and surface waters (estuarine and marine waters included), significant environmental pressures were identified and impacts, where known, assessed.. Based upon the pressures acting upon them, each waterbody was assigned to one of four risk categories:

- 1a – at risk of not achieving good status;
- 1b – probably at risk of not achieving good status;
- 2a – probably not at risk of not achieving good status;
- 2b – not at risk of not achieving good status.

Mariculture was considered a pressure acting on a waterbody and was incorporated into the pressures an impacts analysis in some member states. As an example, in Ireland, bottom culture of mussels, because of its extensive nature was considered as a risk that might impact on the physical structure of the waterbody and was therefore considered to present a pressure under morphological assessment. In terms of other shellfish culture activities, given the distinct lack of information pertaining to the wider impacts on water bodies imposed by aquaculture activities and that aquaculture activities have inherent risks associated with them, all water bodies having licensed aquaculture activities (shellfish and finfish) were classed as 2a – probably not at risk but there is insufficient information to class as not at risk- 2b. It is important to point out that the assessment was not considered definitive and is subject to revision.

In Scotland, it was recognised that the intensity of fish farm activity varies between water bodies (sea lochs). The intensity of activity was the basis for Locational Guidelines for fish farming published by the Scottish Executive. This document classifies coastal waters into three categories, depending on the modelled inputs of nutrients and particulate organic matter. The most highly utilised lochs were assigned to Class 1b. Moderately used lochs were assigned to 2a, and relatively low intensity lochs were assigned to Class 2b.

A number of questions relating to the implementation of the WFD were raised in WGEIM 2004. Some clarification is provided on these in Annex 5 and is summarised below.

It has transpired that aquaculture activities are considered as pressures on the system as a whole and have not been separated out as distinct water bodies. In terms of monitoring, it would appear that temporal and spatial averaging will be carried out within water bodies for all quality elements and chemistry parameters. This ensures that occasional samples that fail to meet the required standards will not govern the overall assessment of that quality element and will only factor in the averaging process.

The conservation status of an area is an important consideration in relation to the WFD considering a waterbody will fail to meet good ecological status if it fails to meet its conservation goals, even if all of the quality elements are considered good. This has particular relevance to aquaculture operations, as many are located within Natura 200 sites.

Chemicals used in mariculture will need to be monitored, as they will likely be considered as specific pollutants under the WFD. Consequently, EQSs will most likely need to be developed on a national basis.

While clarification on some of the issues raised in WGEIM 2004 have been provided and are elaborated in Annex 4 there are others that remain unresolved. In addition, there are other questions that have been raised in relation to the implementation of the WFD and mariculture operations.

- Will exisiting mariculture monitoring programmes fulfil the obligations of the WFD?
- What account will be taken of mixing zones and zones of allowable effect?
- Will monitoring of conservation status be consistent with the requirement of the WFD and existing mariculture monitoring programmes?
- Clarification is still required as to whether extensive mariculture operations (i.e., bottom culture of mussel and oysters) should be considered as aquaculture or fishing activity under the auspices of the WFD?
- The influence of the assessment of chemical quality is still unclear as to whether the detection of medicines associated of aquaculture would leave the activity exposed to mitigation actions under the programmes and measures?

An update of the progress of the EU policy on Sustainable Aquaculture and the European Union Marine Strategy is provided in Annex 5. The main output of the EU policy on sustainable aquaculture in the intervening year since WGEIM 2004 is the publication of draft regulations governing the use of alien species in aquaculture. The EU commission justified the production of these regulations because it was felt that there was a gap in current legislation (e.g., Habitats Directive 92/43/EC) such that the introductions may be effected in a non-deliberate manner or by virtue of alien species being used in non-wild environment.

The EU Marine Strategy in effect is similar (in terms of goals) to the WFD and will clearly cover all territorial waters. What is unclear regarding the EU Marine Strategy is:

- Whether its remit will encompass coastal and transitional waters as defined under the WFD? If not,
- Will the EU Marine Strategy have any impact on Aquaculture activities given that most of these activities within the WFD boundaries (1 nm past the baseline)?

WGEIM **recommends** the potential impacts of new EU legislation on Mariculture activities should continue to be monitored by the group. In addition, the EU marine strategy will extend beyond the limits of the WFD. Aquaculture expansion into more open waters may be impacted by this initiative. It is important that the group (and ICES) be aware of the developments in relation to this legislation.

3.3 Term of Reference d: 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

Models and tools for assessing the carrying capacity of an area of interest for shellfish culture can be classified according to their level of complexity and scope. In this report, we discuss and outline four hierarchical categories of carrying capacity studies as suggested by Inglis *et al.* (2000): *physical*, *production*, *ecological*, and *social carrying capacity*. The assessment of carrying capacity for progressively higher categories of models is based on a sound understanding of preceding categories. We discuss each in brief and the third in more detail as this is the level at which we suggest knowledge is the most lacking and for which science may make the most advances.

(1) *Physical carrying capacity* may be assessed by a combination of hydrodynamic models and physical information, presented and analysed within a Geographic Information System (GIS).

(2) Most scientific effort to date has been directed towards modelling *production carrying capacity* and some of the resulting models have been used successfully to this end. We suggest that further development of these models should pay attention to (i) better modelling of feedback mechanisms between shellfish culture and the environment, (ii) a consideration of all steps in the culture process (seed collection, ongrowing, harvesting, and processing), and (iii) the type of culture technique.

(3) The modelling of *ecological carrying capacity* is still in its infancy. The shortcomings mentioned for models for category 2 carrying capacity estimates are even greater for models in this third category. We suggest that GIS be employed to consider interactions between culture activities and sensitive habitats.

(4) Regarding *social carrying capacity*, the present WGEIM has nothing to add to the recommendations of the 1998 and 1999 WGEIM reports that reviewed the decision support system SIMCOAST. It is further recommended that this last category be calculated only after the preceding levels have been completed so that an unbiased assessment is obtained. This however does not exclude direction from managers (category 4 models) for scientists as to which factors (such as water clarity, specific habitats, etc.) should be evaluated in the third category. It should be the task of the scientists to develop the response scenarios for various indicators for different levels of production and the task of managers to decide which levels are acceptable for the society based on an evaluation of the results from categories 1 through 3.

The WGEIM **recommends** that efforts should focus on the following subjects as they relate to *ecological carrying capacity* studies:

- Studies must be done to better understand the role of various types of bivalve culture installations (and other steps in bivalve aquaculture) in the environment, with a balanced emphasis on both "negative" and "positive" influences;
- Existing models must be made spatially explicit;
- Temporal variation must be built into existing models;
- Models must be validated in a number of locations to evaluate their generality.

The WGEIM also **recommends** that a special session (organised jointly with WGMASC) on *ecological carrying capacity* for shellfish aquaculture be held with the following objectives:

- Update on recent advances in *ecological carrying capacity* research and use;
- Determine similarities with other food production sectors;
- Prepare a review paper with recommendations on future developments.

The group will present the expanded version of this ToR (Annex 5) to the Working Group on Marine Shellfish Culture (La Rochelle, France) in May 2005, for comment with the ultimate goal of requesting a theme session at ICES ASC in 2006/2007. This issue will be progressed by the Chairs of WGEIM and WGMASC intersessionally.

3.4 Term of Reference e: Consider and evaluate the possibility for developing a "sustainability index" concerning environmental interactions of mariculture

The goal was to consider and evaluate the possibility for developing a "sustainability index" concerning environmental interactions of mariculture. Sustainability indices are needed by resource managers who must sort through large amounts of scientific information and make numerous environmental decisions. Sustainability indexes may offer a methodology for monitoring or prioritizing those systems most in need of immediate management attention, and would allow scarce management assets to be applied in the most cost-effective manner. An EU FP6 project is currently under way with the stated goal of reviewing and recommending the best indicators for aquaculture activities. WGEIM will continue to monitor the progress of this project and others in light of a number of criteria regarding the usefulness of sustainability indicators for aquaculture:

1) They must be of the highest scientific credibility and be accepted only after peer review, then must be featured in monitoring and data management protocols.

2) It is important to discern the differences between "sustainability" indicators and "impact" indicators; sustainability indicators should be more comprehensive than impact indicators.

3) Development of SIs for aquaculture should be developed collaboratively.

4) SIs for aquaculture must be simple and cost effective, and example from the Gulf of St. Lawrence, Canada was highlighted.

5) SIs must be flexible enough to be adapted to the local environment in which they will be used.

6) Development of a "sustainability indicator matrix" approach is recommended.

In addition, we emphasize that SIs must be sustainable themselves. The production of information must be practicable at a low cost for the government, public, and the aquaculture sectors and the data from SIs must provide meaningful long-term data series. These time series will need to be housed in data management frameworks at the institutional level, but be universally accessible.

3.5 Term of Reference f: 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

The principles of ecological aquaculture are that it treats and recycles its own wastes to mitigate cumulative environmental effects. Modern aquaculture systems are typified by intensive culture of a single species in open-sea net pens in coastal areas and in land based systems (ponds, tanks). There have been concerns about intensive aquaculture operations being feedlots that are energy intensive, producing nutrient pollution loads comparable to human sewage, and leading to accelerated eutrophication, harmful algal blooms, and unacceptable modification of benthic ecosystems. An approach to mitigate the environmental impacts is by integrating fed aquaculture (finfish, shrimp) with inorganic and organic extractive aquaculture (seaweed, shellfish) whereby the wastes from one resource user becomes a resource (fertilizer, food) for the other.

Integration may address the optimisation of shared resources among various aquaculture users and includes rearing various species in the same production unit, rearing a single species downstream from another, or a combination of these two. The terminology that is used interchangeably to refer to this form of mariculture includes, polyculture, integrated, aquaculture, multi-trophic aquaculture (MTA), ecological aquaculture and sustainable aquaculture.

MTA represents a global aquaculture sector of growing interest and potential development. There are many small experimental systems, within the R&D process. Although they may be of questionable sustainability and economic viability there is some movement towards commercialization of these opportunities. Examples of pilot scale research initiatives are the co-culture of salmon with scallop and oyster, (West Coast of Canada), salmon with kelp and mussel (East Coast of Canada) and sea bream with seaweed and abalone (Israel).

Based on our assessment of the environmental, social and economic considerations the advantages of MTA are: reduction in net effluent discharges; shared operational resources is more cost-effective; production intensification without environmental degradation; diversification of production-market potential, sustainable approach to aquaculture results in public awareness benefits; development of aquaculture in remote coastal communities; and improvement to overall water quality may reduce likelihood of disease outbreaks. The disadvantages are: a technically more complex operation with higher total capital costs; a greater scope of technical expertise is required; handling (e.g., grading, harvesting) of individual species components is more difficult; monitoring & control of disease organisms is more difficult; can require extensive areas for development; maintaining optimal environmental conditions (e.g., temperature, salinity) for multiple species; water quality effects among integrated components may require management (e.g., sea food safety).

There are many technical details of integrated mariculture that need to be addressed through further research. In terms of the management of pond-based integrated aquaculture systems, **WGEIM recommends** that these efforts include, *inter alia*, the development of:

- Algal control strategies;
- Nutritional strategies, including fertilization and supplemental feeds (micoralgae, zooplankton, artemia, polychaetes);
- Methods for mass production of juveniles for system stocking; and
- Optimal fish stocking and fertilization (through modelling).

WGEIM recommends that in respect to open, coastal integrated aquaculture (intensive or extensive) similar research and development initiatives need to be completed. These comprise, for example:

- Evaluation of the efficacy of these systems in terms of environmental impact mitigation;
- Determining an appropriate number and species composition of trophic components (balancing energy/organic materials transfers);
- Identifying and developing management approaches for potential water quality interaction effects (e.g., antibiotic residues); and
- Providing recommendations for changes to regulatory frameworks to accept integrated aquaculture development.

However, to successfully transfer the concept of integrated aquaculture to industry the technical challenges associated with the practical aspects of commercial-scale facilities must be addressed, and these results presented in a context that could be assessed by the investment community that would consider these development opportunities. Future challenges should consider pilot-scale testing of integrated aquaculture systems to permit these issues to be addressed accordingly.

4 Recommendation, future Terms of Reference and closing of the meeting

A number of draft recommendations and terms of reference for future meetings were discussed by the groups and are presented above and in Annex 9. The meeting was formally closed on 15 April at 16:30.

Annex 1: List of participants

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Annex 2: Agenda

Monday, 11 April

09:30 Welcome from DFO, Canada – Dr Joan Kean-Howie
09:45 House keeping and support arrangements- Edward Black
10:00 Introduction of Participants, Review of Terms of Reference, and Designation of Rapporteurs – Chair, All.
10:30 *Comfort Break*
11:00 Presentation and discussion on risk assessment overview document and template. Edward Black, DFO
12:00 ***LUNCH***
13:00 Break out to drafting groups
15:00 *Comfort Break*
15:15 Return to Drafting Groups
16:45 Plenary – Progress update

Tuesday, 12 April

08:00 Plenary Session – overview of work to be carried out - All
09:15 Drafting groups reconvene
10:00 *Comfort Break*
10:30 Drafting groups reconvene
12:00 *LUNCH*
13:00 Drafting groups reconvene
15:00 *Comfort Break*
15:15 Drafting groups reconvene
16:45 Plenary – Progress update

Wednesday, 13 April

08:00 Plenary – Progress to report? - All
09:15 Drafting groups reconvene
10:00 *Comfort Break*
10:30 Drafting groups reconvene
12:00 *LUNCH*
13:00 Field Trip to Canadian Museum of Civilization

Evening Meal sponsored by DFO, Canada

Thursday, 14 April

08:00 Progress distributed and read
09:15 Presentation of Progress and discussion
10:00 *Comfort Break*
10:30 Drafting groups reconvene
12:00 *LUNCH*
13:00 Drafting groups reconvene
15:00 *Comfort Break*
15:15 Drafting groups reconvene
16:45 Days progress distributed and read
17:00 Presentation of Progress and discussion

Friday, 15 April

08:00 Rapporteurs pass draft recommendations and 2005 ToR proposals to the chair Drafting of final document - groups reconvene
10:00 *Comfort Break*
10:30 Drafting groups reconvene
11:00 Discussion of proposed recommendations and 2005 Tor
12:00 *LUNCH*
13:00 Discussions of draft final document and proposals for 2005
15:00 *Comfort Break*
15:15 Final modifications of draft
17:00 End of 2004 meeting

Annex 3: "State of knowledge" of the potential impacts of escaped aquaculture marine (non-salmonid) finfish species on local native wild stocks and complete the risk analyses of escapes of non-salmonid farmed fish - a Risk Analysis Template

Introduction

Fisheries and environmental management decisions today are based on factors beyond traditional considerations of local social, biological and technical characteristics directly linked to the fishery. With the globalization of trade and formation of international trading blocks has come a desire to use international trade agreements to limit barriers to trade. Under these circumstances, environmental and fishery regulations have come under scrutiny as potential non-tariff trade barriers. These trade agreements are not designed to limit a country's ability to protect its natural resources, they simply require that regulations affecting international trade be justified in a fashion that is internationally acceptable and are applied equally to companies both inside and external to the country.

Pre-eminent among international trade rules are those associated with the World Trade Organization (WTO). Under WTO rules, any country found to have implemented barriers to trade without adequate justification can be subject to severe penalties and counter-veiling duties. Further, these duties or penalties are not restricted to the economic sector in which the trade barrier occurred. For example, an unjustified trade restriction in fisheries could result in the affected country, with approval of the WTO, implementing trade restrictions in another economic sector such as the automotive industry sector.

An important tool in designing and justifying restrictive trade actions within the WTO regulatory framework is risk analysis. McVicar (2004) describes risk analysis as "a structured approach used to identify and evaluate the likelihood and degree of risk associated with a known hazard. It leads to the implementation of practical management action designed to achieve a desired result regarding protection from the hazard. Actions taken should be proportionate to the level of the risk. This provides a rational and defendable position for any measures taken to allow meaningful use of resources and for the focus to be on the most important areas that can be controlled, risk management requires that all possible major hazards to the matter of concern should be identified."

Use of Risk Analysis Internationally

In response to concerns about disease transfer and control, WTO accepts the risk analysis protocols developed by the Office International des Epizootic (OIE) as the basis for justifying trade restricting regulatory actions including restriction on movement of commercial and non-commercial aquatic animals. The intent of developing the OIE protocols was to provide guidelines and principles for conducting transparent, objective and defensible risk analyses for international trade. ICES has embraced this approach in their latest (2003) Code of Practice for the Introduction and Transfer of Marine Organisms (hereafter referred to as the ICES Code). One part of the ICES Code is specifically designed to address the "ecological and environmental impacts of introduced and transferred species that may escape the confines of cultivation and become established in the receiving environment". Unfortunately, examples of the application of risk analysis to the development of regulations have not been generally published in the primary scientific literature.

Levels of Protection and the Precautionary Approach

Prior to undertaking an analysis, the terminology used must be explicitly defined together with what constitutes an acceptable level of protection from the risk. Failure to do so compromises the transparency and lack of bias that can be achieved through the risk analysis process.

In particular, terminologies associated with description of the severity of environmental changes and the probability of the changes occurring must be defined as these attributes determine the nature of the resultant management decisions and actions. Terms used in the Australian *Import Risk Analysis on Non-Viable Salmonids and Non-Salmonid Marine Finfish* (AQUIS 1999) are used herein to provide a template for these definitions. In that analysis, there are five categories of severity.

The terminology used to define severity is characterized in terms of three factors: the degree of change experienced in the affected ecosystem or species, the geographical extent of the change, and the temporal duration of the change (from transient to irreversible).

Definition of Severity

CATASTROPHIC:	IRREVERSIBLE CHANGE; TO ECOSYSTEMS PERFORMANCE AT THE FAUNAL PROVINCE LEVEL; OR THE EXTINCTION OF A SPECIES OR RARE HABITAT.
High:	• high mortality for an affected species or significant changes in the function of an ecosystem; • effects would be expected to occur at the level of a single coastal or oceanic water body; • effects would be felt for a prolonged period after the culture activities stop (greater than the period during which the new species was cultured or 3 generations of the wild species, whichever is the lesser time period); • Changes would not be amenable to control or mitigation.
Moderate:	• changes in ecosystem performance or species performance at a regional or subpopulation level but they would not be expected to affect whole ecosystems; • changes associated with these risks would be reversible; • change that has a moderately protracted consequence; • changes may be amenable to control or mitigation at a significant cost or their effects may be temporary.
Low:	• changes are expected to affect the environment and species at a local level but would be expected to have a negligible effect at the regional or ecosystem level; • changes that would be amenable to control or mitigation; • effects would be of a temporary nature.
Negligible:	• changes expected to be localized to the production site and to be of a transitory nature. • changes are readily amenable to control or mitigation.

Note: the term ecosystems in the above definitions refers to water bodies of adequate size that water quality processes therein largely function independently of the processes in adjoining water bodies. For example, a bay or estuary with relatively short water residence time would not be considered an ecosystem. In contrast, a fjord or an inland sea with a protracted residence time might be considered an ecosystem for the purposes of these definitions.

Where the anticipated changes in the three categories fall in a range severity categories the over all severity would be characterized as the average of the severity categories.

For example, if the predicted effect is high mortality of a subpopulation of a species that would be reversible over a couple of generations.

- High mortality of a species is an attribute associated HIGH severity;

- As only a subpopulation is affected the level is MEDIUM severity; and
- the anticipated duration of a couple of generation is a MEDIUM severity characteristic.

The attribution should be HIGH+MEDIUM+MEDIUM = MEDIUM

The response to this level of severity of change is determined by three other factors, the probability of it happening, the certainty associated with that prediction and the acceptable level of protection as discussed in the following sections.

Expression of the probability of a risk being expressed can be achieved in a number of ways. These may be expressed precisely in numerical form or more qualitatively. As numerical quantification is seldom available, the definitions below are of a more qualitative nature.

Definitions of levels of probability

HIGH:	THE RISK IS VERY LIKELY TO OCCUR.
MODERATE:	The risk quite likely to be expressed.
LOW:	In most cases, the risk will not be expressed
EXTREMELY LOW:	The risk is likely to be expressed only rarely
NEGLIGIBLE:	The probability of the risk being expressed is so small that it can be ignored in practical terms.

The assignment of probabilities to particular risks is a critical part of the risk analysis process. In some cases, a fully quantified approach can be taken, but in most cases knowledge of probabilities associated with each of the steps between the driver and the final expression of the risk will not be available. Generally, it will be necessary to adopt semi-quantified or qualitative approaches to estimation of the probability. For example, the probability of enrichment of the sea bed below fish culture units in Scotland is high (based on monitoring data), but the same degree of enrichment will be less probable (moderate to low probability) at fish farms in oligotrophic areas of the Mediterranean Sea.

Previous experience, scientific knowledge, and expert judgment, will be the important factors in assessing the probability of the risk being expressed. However, there will inevitably be a degree of uncertainty in the final assigned probability. This uncertainty expresses the confidence that we can have in the assigned probability. Typically, a risk might be assessed as having low probability of being expressed, but there might be degree of uncertainty in that assessment. For example, fish farms might be considered unlikely to be destroyed by storm (resulting in loss of stock), and therefore this risk would have low probability. However, the quality of equipment maintenance and personnel, differences in degree of exposure at different sites, etc. introduce some uncertainty into this assessment (particularly when applied at the individual farm level), which could therefore be described as having moderate (or high) uncertainty. Overall, the risk of a wreck would be low, with moderate uncertainty.

The number of categories used to describe severity and probability of a risk may vary. There is nothing dictating that it should be 5. It could be more or less. The greater the number used, the more difficult it will be to clearly attribute any particular risk to a specific category. The fewer the number, the more extreme the evaluation is likely to be.

The acceptable level of protection will vary from jurisdiction to jurisdiction, as jurisdictions vary in the level of risk they are willing to take depending on their social and economic conditions. Within the context of justification for trade restrictions, this is likely to be acceptable to WTO as long as the restrictions are equally applied to all traders whether the goods and services in trade are created within the jurisdiction or externally and exported into the jurisdiction. In national or more local regulatory contexts, it implies that regulators can be explicit in the standards that they adopt, and can deliver transparent and consistent decisions.

Severity						
		C	**H**	**M**	**L**	**N**
Probability	**H**	Reject	Reject	Reject	Accept	Accept
	M	Reject	Reject	Accept	Accept	Accept
	L	Reject	Accept	Accept	Accept	Accept
	EL	Accept	Accept	Accept	Accept	Accept
	N	Accept	Accept	Accept	Accept	Accept

Severity = C – Catastrophic, H – high, M – Moderate, L – Low, N – Negligible

Probability = H – High, M – moderate, L – Low, EL – Extremely Low, N – Negligible

Reject = Reject a request for a permit to undertake culture

Accept = Accept the risks associated with permitting the culture to be undertaken

Based on the severity and probability of a risk being expressed, an explicit table for making decisions can be constructed, as above, that illustrates the acceptable level of risk for a jurisdiction. That table might be used to assist resource managers to decide if a license should be issued (Accept) to operate a farm in a certain location or not (Reject).

In recent years, the precautionary principle has emerged as a popular approach to deal with uncertainty in science-based decision making. Article 15 of the United Nations 1992 RIO Conference on Environment and Development defined the precautionary principle as that a "lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation". While the broad sentiment behind the statement is generally agreed upon, the principle has never been accepted as a general principle of international law. A number of factors contribute to the reticence to enshrine the principle in law. The precision of the definition has been problematic. Ronald Doerling, former Vice President of the Canadian Food Inspection Agency, illustrated several of these in an invited plenary speech at Aquaculture 2004 in Montreal, Canada. Among his comments, he pointed out that working interpretations of the principle varied significantly, and that the Swedish philosopher Sandin documented no less than 19 variation in the principle's definition in laws, treaties and academic writings. The versions differed in the interpretation of how scientific uncertainty was evaluated, how severity of consequences is considered, how the costs and risks are to be balanced and from a legal perspective, how the onus shifts to the proponent to prove (if that is ever possible) that the process or product is safe.

The table above combines severity and probability to derive consistent and transparent decisions. However, the table does not take account of the uncertainty in the assigned probabilities. An assessment of a probability as having high uncertainty indicates that the true expression of the risk may differ from the assigned assessment. For example, a risk assessed as of low probability may actually be of extremely low or moderate probability. The precautionary principle indicates that such uncertainty should be taken into account in the assessment and decision-making processes. In terms of the table, a probability of risk of high uncertainty should be considered as equivalent to an assessment of low uncertainty in the immediately higher probability category. In addition, a probability of moderate uncertainty should also be considered as equivalent to an assessment of low uncertainty in the immediately higher probability category for risks of catastrophic severity.

It is clear that, as described here, risk analysis does not overcome all the shortfalls in the definition and application of the precautionary principle, but it does make the assumptions and value judgments much clearer and explicit. If, however, definitions and an explicit elucidation of what constitutes an acceptable level of protection are not well done, the uncertainties and misuse associate with the use of the precautionary principle also become a threat to the objectivity attainable through risk analysis.

Development of WGEIM Risk Analysis

The following assessments of the potential environmental effects of new species being commercially cultured have been formulated following the risk analysis model. The intent in doing so is to create an example of how data might be organized in risk analysis for some newly cultured species. However, individual jurisdictions, must determine the precise nature of the risks they wish to guard against and what, for them, is an acceptable level of protection for their citizens. The accumulated data must then be interpreted in the context of their local ecosystem.

The risk analysis protocol outlined below does not discuss risks associated with the culture of new exotic species. Local jurisdictions should subject new exotic aquaculture to an evaluation under appropriate statutes and other guidelines, such as the ICES Code of Practice for the Introduction and Transfer of Marine Species or its equivalent, prior to permitting their culture. Similarly, the following risk analysis protocols do not discuss potential disease interactions and theraputants other than to encourage member states to apply the aforementioned ICES Code and the OIE protocols. These and individual countries' veterinary drug laws have been designed to control the risks associated with veterinary practices. Finally, no attempt has been made to address risks associated with the quality of the foodstuffs produced, as these risks should be controlled by application of the Codex Alimentarius and associated national legislation.

The Structure of Risk Analysis

For clarity of process, the entire analysis is broken down into 4 components: Hazard Identification, Risk Assessment, Risk Management and Risk Communication. The process and its components are represented diagrammatically in Figure A3.1. The Risk Assessment component is further broken down into 4 subcomponent steps: Release Assessment, Exposure Assessment, Consequence Assessment and Risk Estimation following the generally accepted protocol proposed by Corvelloe and Merkhofer (1993).

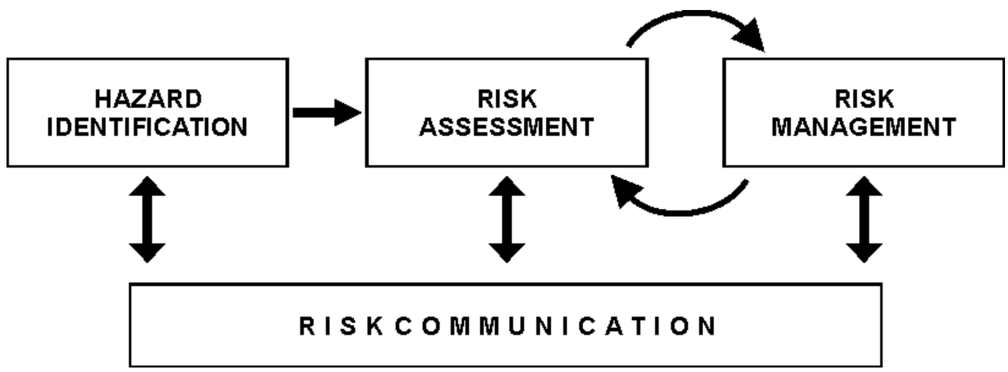

Figure A3.1. The four components of risk analysis (after OIE 2003).

Risk Communication

Risk communication is the most pervasive and one of the most important components of risk analysis. It acts to optimize the transparency and openess of the process, as well as maximizing the aquisition of information, and acceptance of the conclusion of the analysis. Communication with stakeholders at the beginning allows the stakeholders to buy into the analysis and feel they have an influence on the validity of the analysis. In the Hazard Identification phase the communication with the stakholders and other interested professionals helps to ensure that all pertinent formal documentation is included in the analysis. Perhaps more importantly it also allows the analysis to capture information about the area and resources under discussion that is common knowledge to participants but may not be formally documented anywhere. For example fishers often have knowledge of the behavior or distribution of local species that can be important to the analysis but that has not been formally recorded anywhere. During the Risk Assessment portion of the analysis communication helps to ensure that the process itself is transparent. Persons affected by the process can witness how decisions were arrived at.

This helps dispel the feeling that decisions are being made in an arbatrary manner by some faceless and distant bureaucrat about things important to stakeholders and in a manner in which the stakeholders have little influence. During the Risk Management phase communication forms a bridge between the analysis and the implementation of recommendations and post-implementaion monitoring of status of risk development and remediation. Where risk management practices or technologies are to be impleneted to reduce risk to an acceptable level it is important to; communicate what those practices and technologies are, witness that they are implemented and that the practices or technologies are effective.

Figure A3.2. Atlantic Salmon.

An example of the value of risk communication was demonstrated in the management of escaped farmed fish in British Columbia, Canada. The fish farms there are dispersed over an extremely large area with great distances between farms. The population in these areas is very sparce and habitations other than the farms themselves are rare. The cost of monitoring these areas to reassure the local population that few farmed fish are entering the wild could be very high. However, recreation and rural activities bring people to many of these areas intermittently and those people represent a potential source of information about the occurrence of escaped farm fish in the environment. In 1989 the B.C. Ministry of Agriculture Fisheries and Food in cooperation with the federal department of Fisheries and oceans initiated a salmon watch program to collect information from the public on the abundance and distribution of escaped fish. An example of the advertisement is shown in Figure A3.2. These were distributed to a wide variety of shops and organizations and posted on warfs.

There is no single approach to this activity; however, a number of principles should be followed.

Principles of risk communication:

1) Risk communication is the process by which information and opinions regarding hazards and risks are gathered from potentially affected and interested parties during a risk analysis, and by which the results of the risk assessment and proposed risk management measures are communicated to the decision makers and interested parties. It is a multidimensional and iterative process and should ideally begin at the start of the risk analysis process and continue throughout.

2) A risk communication strategy should be put in place at the start of each risk analysis.

3) The communication of risk should be an open, interactive, iterative and transparent exchange of information that may continue after the decision on importation.

4) The principal participants in risk communication include the local, national and international authorities and other stakeholders such as recreational and commercial fishermen, conservation and wildlife groups, consumer groups, and domestic and foreign industry groups.

5) The assumptions and uncertainty in the model, model inputs and the risk estimates of the risk assessment should be communicated.

6) Peer review of risk analyses is an essential component of risk communication for obtaining a scientific critique aimed at ensuring that the data, information, methods and assumptions are the best available.

Hazard identification

Hazard identification is a categorisation step, identifying undertakings (e.g., culture of a new species) dichotomously as a hazard or not a hazard. To prevent the analyst expending unproductive effort, following the OIE risk analysis protocol, the analysis should be concluded if hazard identification fails to identify an increased certainty of the occurrence of an undesirable effect (risk).

Hazard identification should also characterize those aspects of the new species that could increase the likelihood of expression of undesirable effects. The importance of those characteristics is fully evaluated in the Risk Assessment component of the analysis in relation to the specific conditions under which they are likely to occur. Rather than duplicate the listing of these charateristic here, they will be presented in the section on Risk Assessment where the reason for their inclusion will be more apparent.

Risks examined are defined by our understanding of ecosystems, and policy decisions are the province of regulators. What constitutes valued ecosystem components, and the nature of unacceptble change, may vary from jurisdiction to jurisdiction. For example, if a society defines volume and security of food supply as its primary marine ecosyem need, it may value diversity in an ecosystem less that another society for whom marine food supply is less important. These are socio-economic valuation issues that are beyond the scope this paper.

The statement that risk anaysis is a tool to help manage the effects of man's activities on biotic resources is deceptively simple. The key point is that the intent is to manage environmental change, not merely individual human activities. For example, there have been calls to control the escape of fish from aquaculture. That however, only focuses on managing the occurrence of the escapes, not the effect of the escapes on ecosystem function or species survival. The actual effects that should be managed are more along the lines of the effect of escaped fish on the food supply or space resource available to wild fish populations, or the effect of genetic interactions between wild and cultured fish on the fitness of the wild fish.

Effective management requires context for each decision. It is of little value to control the effect of an activity in one location if other activities impacting the same ecosystem ensure that the same effect will occur anyway. To elaborate on the example from the previous paragraph, a decision might be made to prevent aquaculture of a non-local strain because they could escape and disrupt the genome of a native population. If however, public enhancement of the wild population with a non-endemic strain has already occurred, then disruption of the genome of the local strain has already occurred and the incremental change from aquacuture activities may be insignificant.

Risk Catagories

The specific risks to be managed are dependent on many factors. Some of the risks are the result of legislative mandates or international agreements. Others may be derived from special socio-economic concerns. Legislation and policies of the national or regional authority may identify some risks that need to be managed. For example, in Canada there is the Species at Risk Act that necessitates the protection of species or populations designated as being at risk of extirpation. This requires regulatory bodies to protect not simply the species, but also the habitat that support them untill such a time as they are removed from the list of species at risk. International agreements, such as the International Convention on Biodiversity, may also define attributes that require protection. Cultural factors may enter into considerations of what risks to protect. For example, clams and salmon, are important sources of food, income and cultural activities for the first nations peoples on Canada's west coast.

Listed below is a suggested initial list of risks to be examined for aquaculture in marine ecosystems. These should be elaborated to meet the specific socio-economic needs of the country considering implementation of risk analysis. These environmental risks are drawn primarily from experience with temperate zone salmon and shellfish culture. Some of the forces involved in the expression of the risks may differ in degree between events and locations. Also, over time, our understanding of the mechanisms will evolve requiring examination of new parameters to better define the severity and certainty of expression of a risk. Even so, with the historical experience gained in environmental interactions of temperate mariculture globally, it seems unlikely that new types of environmental effects are going to occur that are unique to newly cultured marine species.

An initial examination of the experience with temeprate aquaculture would suggest that at least five broad catagories of environmental effects or risks are generally associated with temperate marine aquaculture.

1) Changes in primary producers
    a) Abundance (Macroalgae and Marine Angiosperms)
    b) Composition (Harmful microalgae)
2) Changes in fitness of wild populations due to genetic intergradation

3) Changes in macrobenthic populations

4) Changes in trophic resources

5) Changes in habitat (physical and chemical)

Prior to initiating a risk analysis, it is impotant to clearly identify the end point characteristic to be managed. Confusion can sometimes arise between predicting the change in the value of a parameter that is part of the sequence of events (logic model) and that of estimating the overall probability (together with its associated uncertainty) of the actual environmental risk being expressed. This is well illustrated by the examination of the effect of sea lice on wild populations cited earlier (McVicar, 2004). The true end point was the abundance of the wild salmon populations, not the very contentious abundance of sea lice.

It may be noted that there are considerable similarities between the categories of environmental effects or risks listed above and the quality elements employed under the EU Water Framework Directive (WFD) to express the ecological status (quality) of surface and coastal marine waters. The WFD will be the primary mechanism for the assessment and improvement of the quality of aquatic environments in the EU. The assessment process is to be based upon a series of biological elements, supported by a range of hydromorphological, and chemical/physico-chemical elements (Table A3.1).

Table A3.1.

TRANSITIONAL (I.E., ESTUARINE) WATERS	COASTAL WATERS
Biological elements	
• Composition, abundance and biomass of phytoplankton • Composition and abundance of other aquatic flora • Composition and abundance of benthic invertebrate fauna • Composition and abundance of fish fauna	• Composition, abundance and biomass of phytoplankton • Composition and abundance of other aquatic flora • Composition and abundance of benthic invertebrate fauna
Hydromorphological elements supporting the biological elements:	
Morphological conditions: • depth variation • quantity, structure and substrate of the bed • structure of the inter-tidal zone Tidal regime: • freshwater flow • wave exposure	Morphological conditions: • depth variation • structure and substrate of the coastal bed • structure of the inter-tidal zone Tidal regime: • direction of dominant currents • wave exposure
Chemical and physio-chemical elements supporting the biological elements:	
General: • Transparency • Thermal conditions • Salinity • Oxygenation conditions • Nutrient conditions Specific Pollutants: • Pollution by all priority substances identified as being discharged into the body of water • Pollution of other substances identified as being discharged in significant quantities into the body of water.	General: • Transparency • Thermal conditions • Salinity • Oxygenation conditions • Nutrient conditions Specific Pollutants: • Pollution by all priority substances identified as being discharged into the body of water • Pollution of other substances identified as being discharged in significant quantities into the body of

The WFD biological elements concerning phytoplankton and benthos correspond to the broad categories of risks in changes to primary producers and macrobenthic populations. Changes to trophic resources and the risks of reductions in fitness through genetic interactions are linked to WFD quality elements concerned with fish fauna. The risks associated with habitat changes correspond to WFD hydromorphological, and chemical/physico-chemical elements.

To establish the severity for each of the potential risks it is necessary to determine:

1) When present, what is the geographic scale of the change?
2) When the event occurs in conjuction with mariculture activities, do the changes appear to be primarily occuring in one or two affected species or are changes detected at the level of ecosystem or faunal province?
3) When present, is the degree of change in the ecosystem large?
4) When the change is species specific, how extensive (individuals, sub-poulation, strain, metapopulation or entire species) and severe is the change to the species?
5) How persistant are the changes or are they irreversible?

Logic Models for Expression of Environmental Risks

For each of the risks/effects, prior to undertaking an analysis, we should outline what is known of the process that leads to the expression of the effect. Often we lack a complete understanding of that process. However, there is usually an understanding of many of the factors involved. To the degree possible, we should explicitly identify factors that contribute to the change(drivers), what factors modify or prevent the change(modifiers), and how is the change expressed temporally and geographically. It is also very important to identify what other human activities in the area might contribute to the expression of the same risks.

For the risks identified in the preceeding section, below are a list of possible end points, a logic model and a short summary of previous experience for each of the environmental risks of aqaculture, as they have been experienced in nothern temperate regions. End points represent the measurable change that stakeholders or the public would recognize as the expression of risk they wish to avoid. For example, with eutrophication the public seldon recognize the hypernutrification component of the process but they do recognize their wateways being clogged by macrophytes or changes in the color of the water caused by high abundance of phytoplankton (plankton blooms). The logic model is a process model that shows what is required (e.g., nutrients +algae) to reach the undesired end point (e.g., a plankton bloom) what might prevent the exression of the effect (e.g., a plankton community that is light limited or high dilution rates). The model should express its outputs in terms of the parameters used to evaluate the severity of change for example; the duration of the change, from irreversible to an effect that dissapears as soon as the input ceases, the geographic extent (just at the farm site, an entire bay or a larger area) and the effect of the outcome (for increased phytoplankton it might include the occurrence of toxic blooms as opposed to the occurrence of a change in water color without any toxicity.)

Once the logic model has been recognised and agreed as a statement of the steps involved in the expression of the risk, it is possible to begin to collate information on the processes operating at each of the steps. This very quickly leads to an improved understanding of those steps for which clear information exists, and those steps for which information is relatively lacking. This can have an immediate effect of directing research resources to the areas of weakness to improve the knowledge base underpinning the the logic model.

The next stage is to estimate, from the collated information, the probability of each step occurring. Steps where good information exists should allow expression of this probability with low uncertainty. Steps where information is relatively sparse may lead to higher levels of uncertainty in the estimated probabilities.

1 Risk of change in algal abundance

a) Macroalgae

End point – Enhancement of macrophytes

Previous experience – There are limited studies of the occurrence of this phenomenon. However, where fish farm production is executed in waters close to shore it appears there is potential for increased macrophyte abundance. Documented in the Baltic archipelagos, and the Canadian Maritimes, macroalgae do appear to respond to the presence of fish farming with increased abundance. The geographic extent is generally limited to the area in the immediate area of the culture facility and is expected to not significantly outlast the duration of the aquaculture facility.

DRIVERS	SIGNIFICANTLY INCREASED ABUNDANCE OF LIMITING NUTRIENTS (TYPICALLY NITROGEN IN MARINE WATERS BUT PHOSPHORUS MAY BE SIGNIFICANT IN ESTUARINE ENVIRONMENTS).
	Substrate in the euphotic zone within the nutrient plume.
	Seed source for macrophytes
	Eutrophication
SOURCES	Aquaculture
	Other nutrient sources, e.g., – Urban – Agricultural – Tidal
MODIFIERS	Dilution regimes
	Depth of euphotic zone
TEMPORAL EXPRESSION	Unclear, but likely to be seasonal and unlikely to be expressed outside of growing season once nutrient source removed
GEOGRAPHICAL EXTENT	Dependent on current derived dilution and distribution of nutrients and substrate
OUTCOMES	Increased habitat heterogeneity that is usually associated with increases in local secondary productivity
	Increased macroalgae resulting in increased habitat for sheltering prey species
	Increased macroalgae can impede vessel traffic
	Increased macroalgae may affect aesthetic values for residence and tourism.

b) Microalgae

End point – increase in occurrence of water discoloration due to algal blooms

Previous experience –It is not clear whether significant changes in microalgal abundance occur in association with fish culture. Though considered possible, it has not been demonstrated to be linked with salmon farming in Europe, North America or Chile. Blooms in the inland sea of Japan have been linked to urban nutrient input. Korean fish farming occurs in areas with algal blooms, but it is also located downstream from the high nutrient input from the Yellow River. Blooms in Laguna De Bay in the Philipines may be associated with fish farming. In contrast, changes in microalgal abundance have been associated with shellfish culture, although the extent and duration of those changes seems dependent on enclosed waterbodies with protracted residence times and the duration of the culture activities.

DRIVERS	NUTRIENTS
	Temperature
	Seed sources
Sources	Shellfish culture activities
	Fishfarms
	Other nutrient sources, e.g., – Urban – Agricultural – Tidal
Modifiers	Residence times/dilution regimes
	Transport regime
Temporal expression	Likely only to occur during growing season. Once source of nutrients is removed or shellfish culture concluded, it is unlikely to persist.
Geographical extent	Dependent on current derived dilution regimes and distribution of nutrients.
Outcomes	Potential for significant increases or decreases in algal abundance and for the occurrence of harmful algal species

2 Changes in fitness of wild populations due to genetic integradation

End point – Significant decline in survival due to genetic changes resulting from interbreeding with cultured organisms.

Previous experience – No evidence has been found that commercially cultured aquatic organisms have novel alleles otherwise absent from feral populations of the same species. Differences in allelic frequencies have been noted. Interbreeding has been documented between escaped and feral Atlantic salmon. Interbreeding is more likely to occur in areas close to the location of the escape. The effect of intergradation is likely to be proportional to the relative number of wild and cultured organism interbreeding. Where only a few individuals are involved, the effects are likely to be less. Where relatively large scale genetic intergradation has occurred, there has been reduced fitness and survival of the feral population. Where studied, hybrids of single interbreeding events rapidly disappear from the feral population and the effect is likely to be reversable through natural selection over a period of a few years. Where large scale repeated escapes occur, the effects are likely to be larger and the consequences unpredictable. Metapopulation dynamics are likely to buffer the effects of occasional intergradation events, but not buffer effects from repeated large scale events.

DRIVERS	PROPORTION OF WILD POPULATION INTERBREEDING WITH ORGANISMS ESCAPING CULTURE
	Relative difference between wild and cultured fish genome
SOURCES	Shellfish culture activities
	Fishfarms
	Strays from other endemic populations
	Genetic effects of – Stock improvement – Transfers – Enhancement – Genetic selection associated with fishing activities
MODIFIERS	Metapopulation structure
	Population size (effects of drift and inbreeding)

	The effects of selection by other human activities
Temporal expression	Where intergradation occurs it is likely to affect at f1 generation.
	Impact on f2 and beyond are unclear.
Geographical extent	Dependent on migratory behaviour and breeding distribution but most likely in areas adjacent to escape.
Outcomes	Reduced fitness of feral population

This is a complex area to evaluate. Initially it should be demonstrated that the population/species in question is able to respond to selection. Without effective selection long-term fitness cannot be optimized. An indication of whether selection is likely to be effective is available by through an examination of the effective population size.

The ICES Working Group on the Application of Genetic to Fisheries and Mariculture (WGAGFM) examined the literature on the ratio of effective population size to survey population size in their 2004 report. In table 2.1.4.1 of that report they list values and ranges associated with a number of species including sea bass, Atlantic cod and Pacific oyster (Table A3.2).

Table A3.2. N_e/N ratios for selected marine and freshwater species. Note that both the method of calculating N and the definition of N can affect the ratio. (VF Variance in gene frequencies, LD Linkage Disequilibrium, T Temporal Method, MUT mutation drift equilibrium). From report of the ICES WGAGFM 2004.

Species	N_E/N	Method	Reference
Menhaden	<0.0025	MUT	Bowen and Avise 1990
Black sea bass	0.005	MUT	Bowen and Avise 1990
Pacific oyster	<0.000001	VF	Hedgecock *et a!.* 1992
Sea bass	0.27–0.40	LD	Bartley *et a!.* 1992
Chinook salmon	0.0 13–0.043	LD	Bartley *et a!.* 1992
Steelhead trout	0.73	T	Ardren and Kapuscinski 2003
New Zealand snapper	0.00001	Various methods	Hauser *et al.* 2002
Red drum	0.004	T	Turner *et al.* 1999
Red drum	0.001	T	Turner *et al.* 2002
Vermilion snapper	0.00 15–0.0025	LD	–
Northern pike	0.03–0.14	T	Miller and Kapuscinski 1997
Atlantic cod	0.00004	T	Hutchinson *et al.* 2003
Chinook salmon	0.02–0.56	Various methods	Shrimpton and Heath 2003

Published effective population sizes required to avoid the long term effects of interbreeding and genetic drift range from 500 to 5000 (Franklin, 1980; Lande, 1995). These are only rude approximations but give a starting point for discussion.

The relationship between the relative number of cultured fish interbreeding with the wild population and its effect on the fitness of the wild population is not well quantified.

Some level of interbereding between wild and cultured populations can be tollerated by the wild population. In the Atlantic large numbers of cultured Atlantic salmon have been foiund in the wild fishery aned have been found in the fisheries for over a decade. Wild salmon continue to survive though their survival rate has decreased. The contribution of interbreeding to reduced survival in Atlantic salmon is not clear as many other factors, such as by catch and climate change and habitat distruction, are also changing and would be expected to also reduce salmon survival.

The contribution of the geneome of cultured populations to the composition of wild populations. While the numbers of fish in both the wild and cultured components of these events were small it is interesting to note that markers from the genome of the cultured fish appeared to rapidly disapear from the wild population.

3 Changes in macrobentic populations

End Point – Reduction in the productivity or diversity of significant portions of specific habitats

Previous experience – The benthic community response to particulate loadings from aquaculture (finfish or shellfish) follow the same pattern as seen in response to other sources of organic particulate loadings. The area of highest loadings is generally centered under culture activities. The level of response varies from increases in diversity and abundance at low loading levels, to loss of macrofauna at high loadings. Once loadings cease, recovery typically occurs within months or, at higher loadings, in 2 to 4 years.

DRIVERS	AMOUNT OF UNEATEN FEED
	Amount of faeces or pseudofaeces produces
	Amount from other sources of solids
Sources	Shellfish culture activities
	Fishfarms
	Periodic recruitment phenomenon
	Effects of other human activities: – human sewage – log storage areas – upland construction activities
Modifiers	Bottom current regieme
	Fallowing and harrowing practices
	Density of culture sites
Temporal expression	Dependent on level of accumulation but on average approximately 1 year. Where accumulation is severe and currents are low, as much as 2 to 4 years.
Geographical extent	From an individual site, usually in the immediate vicinity (within 30 to 100 m) of the production facility but in rare instances may be more dispersed (up to a km.).
Outcomes	Depends on level of accumulation of organics but is expected to include all or some of the pattern described below.
	Areas of high accumulation may be devoid of macrofauna with community shifting from macrofaunal domination to domination of bacterial community. In extreme circumstances benthos may become anoxic and *Beggiatoa* colonies may become apparent.
	In areas of slightly less accumulation of organics, macrofaunal communities will be typified by high production of a few opportunistic species (e.g., *Capitella* sp.)
	As levels of organic accumulation decrease, the biomass of macrofauna decreases but the diversity increases
	As levels of accumulation decrease further toward those of natural loadings, the faunal diversity and biomass decreases to background levels.

4 Changes in trophic resources

End Point – Changes in the abundance of endemic trophic resources

Previous experience – Extensive bivalve culture consumes a portion of the endemic production of planktonic particulate organic material. In a limited number of circumstances on the scale of enclosed bays, extensive high density shellfish culture has been associated with reduced particulate carbon loadings and reduced bivalve growth rates. Similarly reduced growth has been noted in high density raft culture of bivalves. Those bivalves on the downstream side (where currents are broadly unidirectional) or in the center of the raft (where currents change direction with tides) can be smaller (i.e., grow less rapidly) than those along the upstream side of the raft.

There is a limited amount of information on the consumption of wild prey by cultured fishes. Salmonids cultured in marine cages have been shown to consume endemic invertebrate thigmotatic or fouling organisms. To a much lesser degree, they have been seen to consume juvenile (post larval) fish. No evidence has been presented to evaluate the effect of consumption of the invertebrates, although they are unlikely to represent a significant food resource to the cultured fish. Analysis of the level of consumption of juvenile wild fish suggests that it is unlikely that predation by caged fish would measurably affect the survival of the wild fishes.

DRIVERS	NUMBER AND BIOMASS OF CULTURED ORGANISMS
Sources	Shellfish culture activities
	Fishfarms
	Natural recruitment phenomenon
	Changes in climatic and oceanic regimes (carrying capacity)
	Effects of other human activities: – Enhancement activities (e.g., artifical reefs) – Fishing
	Organisms that have been introduced or spread from other areas.
Modifiers	Degree to which tropic requirements may be supplemented by feed supplied by aquaculture
	Degree to which culture facilities restrict culture organism’s access to wild trophic resources
	Human harvests
	Oceanic regime changes and natural variation in the abundance of wild organisms.
Temporal expression	Recovery of wild trophic resources (organisms) is dependent on the degree to which production (as opposed to standing stock) of wild organisms is affected.
	If production of trophic resources is unaffected, recovery is expected to immediately follow cessation of culture activities.
	If production has been affected, the return to historical levels will depend on recruitment and growth of natural populations. If the affected organisms are low in the food web, the recovery period is expected to be short, in the order of a year or two.
Geographical extent	Dependent on the distribution and intensity of culture activities in relation to the geographic distribution of the prey species.
Outcomes	Depression in local abundance of trophic resources

5 Changes in physical habitat.

End Point – changes in the physical habitat (currents and physical habitat)

Previous experience – Though not well documented in the literature, experience has shown that culture structures can influence current speeds and direction in the immediate vicinity of the structures. Areas of reduced currents are generally experienced in the lee of culture facilities. At shallow sites, the area under large culture facilities may experience increased current speeds, and this may consequently alter the local pattern of sediment accumulation. For example, a depositional area under a cage system may be altered to an erosional environment with consequent greater dispersion of particulate material leaving the culture system. These changes though are thought to last only as long as the culture facilities are inplace and to influence only a small area in the immediate vicinity if the culture facility. As the area affected is small, it is anticipated that individuals of species occupying the affected area may be affected but it is unlikely that whole ecosystems or species will experience significant effects.

DRIVERS	Number of culture systems
	Increased habitat heterogeneity
	Increase in areas for plant and animal settlement
	Redirection of currents
	Changes in current velocities
SOURCES	Shellfish culture activities
	Fishfarms
	Natural erosional and depositional events
	Storm
	Failure in macrophyte recruitment
	Effects of other human activities – artifical reefs, – harbour construction, – upland construction – fishing
MODIFIERS	Structural design
	Orientation of structures
	Macrophyte distribution
	Placement of structures relative to currents
TEMPORAL EXPRESSION	Limited to the duration of the structures
GEOGRAPHICAL EXTENT	Proximate to the structures
OUTCOMES	Changes in the dilution and erosional schemes

European DPSIR and Logic Models for Risk Analysis

Environmental indicators are currently being widely used to reflect trends in the state of the environment and monitor the progress made in realizing environmental policy targets. As such, environmental indicators have become indispensable to policy-makers. Environmental indicators are used for three major purposes in relation to policy-making:

- to supply information on environmental problems, in order to enable policy-makers to value their seriousness;
- to support policy development and priority setting, by identifying key factors that cause pressure on the environment;
- to monitor the effects of policy responses.

Communication is the main function of indicators: they should enable or promote information exchange regarding the issue they address. Environmental indicators may be used as a powerful tool to raise public awareness on environmental issues. Providing information on driving forces, impacts and policy responses, is a common strategy to strengthen public support for policy measures.

The European Environment Agency has developed an indicator framework known as the DPSIR Framework (Drivers, Pressures, State, Impact, Response). It is essentially a descriptive framework, and reflects a systems analysis view of the relationships between the environmental system and the human system (Figure A3.3)

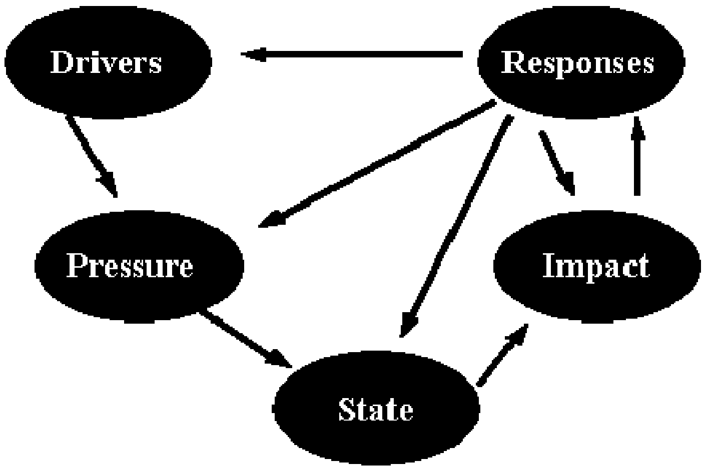

Figure A3.3.

According to this view, the causal pathway through which human activities affect the physical environment can best be understood by means of this model that links **D**riving Forces with the **P**ressures they create on the **S**tate of environment, and the **I**mpact this has on ecosystems or human health. **R**esponses by governments, economic actors or the public aim to influence one or several of the D, P, S or I. From the policy point of view, the purpose of the DPSIR Framework is to present clear and specific information on each element in the chain that leads to policy decisions.

There are many similarities between the development of logic models for risk analysis and the DPSIR system. For example one of the risks associated with aquaculture is that the release of nutrients may affect macroalgal communities. As an example of the application of the DPSIR approach to aquaculture, the elements in the Logic Model for this risk outlined in the previous section are presented below using the DPSIR framework:

DPSIR ELEMENTS	LOGIC MODEL ELEMENTS
Drivers	Aquaculture And other nutrient sources, such as urban areas, agriculture/forestry, and tidal exchange.
Pressures	Inputs of nutrients. *Note: The significance of inputs will be modified by factors including:* – Dilution regimes, – Depth of euphotic zone, – Substrate in the euphotic zone within the nutrient plume, – Seed source for macrophytes.
State	Concentrations and distribution of (particularly) limiting nutrients. *Note: Limiting nutrients (typically nitrogen in marine waters, but phosphorus may be significant in estuarine environments) will be particularly important.*
Responses	Responses are not addressed by Hazard Evaluation Logic Models, but are covered by later stages of the Risk Analysis process, i.e., Risk Management.

The DPSIR framework is useful in describing the relationships between the origins and consequences of environmental problems, but in order to understand their dynamics it is necessary to focus on the links between DPSIR elements. For example, whether society 'Responds' to impacts depends on how these impacts are perceived and evaluated; and the results of 'R' on the 'D' depends on the effectiveness of the Response. Obviously, the real world is far more complex than can be expressed in the simple causal relations in this systems-based analysis. There is arbitrariness in the distinction between the environmental system and the human system. And, moreover, many of the relationships between the human system and the environmental system are not sufficiently understood or are difficult to capture in a simple framework.

Weaknesses in the DPSIR approach therefore arise from the essentially descriptive nature of the indicators involved. It is difficult to take account of the certainty of suggested impacts occurring, or the uncertainties in both the expression of the description of the system and the severity of the consequences of the impacts. It is in this context that the Risk Evaluation can progress beyond the DPSIR approach and contribute more realistically to decision-making. Formalized Risk Evaluation requires the relationships between drivers/pressures and impacts to be expressed through logic models. In turn, this enables a more explicit and transparent assessment to be made of the reliability of the evidence supporting each of the steps in the model, and probabilities of occurrence of particular impacts to be better assessed.

Risk Assessment

1. Release assessment

Release assessment is the process of developing a description of the relevant characteristics of the risk source that establishes its potential for creating a negative environmental effect by releasing some factor into the environment. It consists of a description the pathway(s) necessary to 'release' (that is, introduce) a hazard into a particular environment. The release assessment describes the 'release' of each of the hazards under each specified set of conditions with respect to amounts and timing, and how these might change as a result of various actions, events or measures. Examples of the kind of inputs that may be required in the release assessment are:

a) Biological factors

- Species, strain or genotype;
- Age of animals.

b) Area Specific factors

- Density and distribution of culture facilities, numerical abundance in each containment unit;
- Evaluation of surveillance and control programs, and zoning systems of local authorities;
- Potential release sites due to transport, culture and treatment.

c) Species specific factors

- Schooling behaviour;
- Exploratory behaviour;
- Jumping behaviour;
- Spawning behaviour;
- Rubbing or nibbling behaviour;
- Effect of handling behavior (e.g., jumping);
- Effect of starvation;

- Effect of medication;
- Effect of external predators or activity on or about containment structure;
- Effect of genetic manipulation;
- Effect of domestication on behaviour.

d) Culture Facility Factors

- Degree of isolation of cultured organisms from the environment;
- Certainty of containment failure.

If the release assessment demonstrates no significant risk, the risk assessment need not continue.

2. Exposure assessment

Exposure assessment is the process of developing a description of the relevant conditions and characteristics of the environment exposed to the risk agents. It consists of describing the biological pathway(s) necessary for exposure of the local environment to the risk agent.

The exposure is estimated for specified conditions with respect to amounts, timing, frequency, duration of exposure, routes of exposure, and the number, species and other characteristics of environment exposed. Examples of the kind of inputs that may be required in the exposure assessment are:

a) Biological factors

- Presence of species for potential hybridization/intergradation
- Genotype of con-specifics
- Properties of the cultured fish that would affect interbreeding (e.g., mate preference, timing of spawning, and rate of survival to spawning).
- Success as a predator
- Success at avoiding predation
- Success as a competitor for resources
- Migratory or dispersal habits
- Ability to find spawning aggregations
- Migratory behaviour

b) Area Specific factors

- Aquatic animal demographics (e.g., presence and distribution of known con-specifics, competitors, predators and prey),
- Human and terrestrial animal demographics (e.g., possibility of scavengers, presence of piscivorous birds, sport and commercial fishing activity),
- Geographical and environmental characteristics (e.g., hydrographic data, temperature ranges, water courses).

c) Species specific factors

- Whether there has been significant genetic differentiation between wild and cultured con-specific strains,
- Abundance of con-specifics, predators, prey and competitors.
- Waste disposal practices.

If the exposure assessment demonstrates no significant risk, the risk assessment should conclude at this step.

3. Consequence assessment

Consequence assessment is the process of developing a description of the relationship between the exposures to the risk agents and the consequence. It includes identifying the potential biological and economic consequences. A causal process must exist by which exposures to a hazard result in adverse health, environmental or socio-economic consequences. Examples of consequences include:

a) Direct consequences

- The scale and potential significance of interbreeding with local populations,
- Adverse, and possibly irreversible, consequences to the environment

b) Indirect consequences

- Surveillance and control costs,
- Compensation costs,
- Potential trade losses,
- Adverse consumer reaction

4. Risk estimation

Risk estimation is the process of characterizing uncertainty and possible risk consequences. It consists of defining the uncertainty in associated with prediction of the consequences and integrating the results that with the consequence assessment to produce overall measures of risks associated with the hazards identified at the outset. Thus risk estimation takes into account the whole of the risk pathway from hazard identified to unwanted outcome.

Qualitative assessments should always be performed and quantitative assessments should be used to further inform the outcome of the qualitative assessment. Because of its more precise nature, quantitative analysis is necessarily more focused in nature and has the potential to be more precise (but probably less accurate) over all the potential aspects of a hazard.

For a quantitative assessment, the final outputs may include:

- The various populations of *aquatic animals* and/or estimated numbers of *aquaculture establishments* or people likely to experience health impacts of various degrees of severity over time;
- Probability distributions, confidence intervals, and other means for expressing the uncertainties in these estimates;
- Portrayal of the variance of all model inputs;
- A sensitivity analysis to rank the inputs as to their contribution to the variance of the risk estimation output;
- Analysis of the dependence and correlation between model inputs.

Evaluation Models used for risk Assessment

Models, mathematical or qualitative (logical), can be used to describe each of the components (release, exposure and consequence assessment as well as risk estimation) of a risk analysis. Care must be taken in the choice and application of the models used. The models may be qualitative or quantitative in nature, and quantitative estimates may be made on the basis of correlative or mechanistic models. Generally, transition from qualitative towards mechanistic models of risk reduces the uncertainty, but narrows the focus on the nature of the risk examined. For example, a qualitative analysis of the impact of environmental risks associated with fish farming may include a broad array of changes to the physical, chemical and biological features of the environment. Typically, a quantitative analysis would be much more restrictive, focusing on a single aspect for which much is known about the mechanisms involved in the expression of the risk. An example of where today's knowledge might allow development of the more restrictive but more quantitative type of model would be a model of risk associated with the effect of fish farming on sediments under a near shore salmon farm cage. This focusing down on a narrower evaluation of risk in a quantitative risk analysis is inevitable as our understanding of the basis of many interactions is not understood mechanistically to a level where numerical quantification is possible. For this reason, it is recommended that qualitative risk analysis always be undertaken and quantitative risk analysis should be used, where possible, in support of the qualitative analysis.

Qualitative and correlative approaches to risk analysis also have weaknesses that need to be considered in their application. In qualitative risk analysis, the model of the sequence of events required to have a risk expressed must be carefully formulated. McVicar (2004) illustrates a kind of failure that can occur because inadequate attention has been devoted to the analysis of events rather than an analysis of what leads to the endpoint of the risk in question being realized. The hazard in question was salmon farming and the risk was that sea lice infections on the farms could affect the abundance of wild salmon. Observations made include that: 1) Individual fish that carry a large number of sea lice on them can develop lesions and die. 2) Farmed fish occasionally suffer sea lice infestations (which they must have acquired from the wild fish populations) 3) Wild fish in the vicinity of a farm experiencing lice infestation carry higher numbers of lice than fish from areas without fish farms. It has been proposed that this constitutes proof that fish farms constitute a serious risk to the wild fish populations, because sea lice kill salmon and fish farms can transfer sea lice to wild salmonids. McVicar puts forward a number of reasons why this model is flawed. The most significant of these is that the mechanism of death for a single fish does not necessarily translate to a mechanism controlling the abundance of a stock or species. When examined, the data both from before the advent of fish farms and data from the period since the advent of fish farm do not show a correlation between the level of lice infestation in the wild fish populations and subsequent level of survival of wild salmon.

Correlative risk analysis treats the sequence of events leading to a risk as a complete unknown and instead uses a more actuarial or experiential approach. Kolar and Lodge (2002) created a quantitative risk analysis based on the correlation of life history characteristics of fish species that were successful and species that were not successful in invading the Great Lakes. This constituted a major step toward risk evaluation and effective regulation of intentional fish introductions into the Great Lakes. However, because we do not understand the precise mechanism that caused each of the fish species to establish in the Great Lakes, it would be folly to extrapolate the use of this model to, for example, evaluate the risk of fish species introduced into Great Slave Lake before the model has been tested in wide variety of other lakes including lakes similar to Great Slave Lake.

In addition to environmental/ecosystem factors, the risk assessment phase of the analysis should also take account of the general supporting framework within which the aquaculture industry operates. In many jurisdictions, risk management actions are already in place in the form of regulatory controls on, for example, the location and scale of aquaculture units. Such controls can be viewed as mechanisms to assist the national industry as a whole to limit their contribution to particular risks. Structures may also be available at national or more local level to impose particular conditions on specific localities (e.g., a bay, or fjord) or farms, and thereby tailor regulation to the needs of particular areas and developments. In some jurisdictions, zoning schemes have been developed to regulate development. Zoning is a mechanism to ensure that developments occur in an orderly and planned manner, and that agreed local environmental or societal goals are met, thereby reducing the risks to the industry and the receiving ecosystems.

Codes of Practice, led by the industry or by regulators, are also valuable mechanisms for reducing risk (e.g., of disease transfer, or of escapes), provided that the individual farm operators recognize the value of the Codes and adhere to them. In the late 1990s, the Chilean salmon farming industry developed a "Code of Good Environmental Practices for Well Managed Salmon Farms" that was tied environmental friendly labelling for products from farms adhering to the Code. Some of these codes of practice are linked more closely to the achievement of internationally recognized standards, such as the ISO 14000 (Environmental Management Systems) standards. In British Columbia approximately 50% of the salmon farming industry has developed corporate environmental management systems that meet and have been registered to the ISO 14000 standard. Linking the codes of practice to quality certification programs makes conformation to those standards more compelling to the industry. While Codes of Practice typically represent Standard Operating Procedures, the integration of these protocols within the framework on an ISO-14000 Environmental Management System requires that the significant environmental aspects of an aquaculture facility include a quantifiable measure of continual environmental improvement. This is attained through the implementation of specific environmental objectives/targets, monitoring/research programs, training, record-keeping, and a third-party audit function.

One of the primary considerations in the planning of aquaculture developments is the ease of access to the necessary support infrastructure and services. Farms may be located in remote areas, and this brings the potential for reduced ease of access to veterinarians, maintenance workers, appropriate emergency response following equipment failure, etc. In many cases, companies have become more accustomed to the recognition of these risks, and have developed internal mechanisms and resources so that their responses can be quick and effective. However, the absence of such arrangements is likely to increase the severity of any particular incident.

Broader aspects of infrastructural support also need to be taken into account. As noted above, the quality and reliability of transport links can be very important in responding to incidents. Equally, the risks associated with routine operations such as transport of young stock to grow-out locations increase as the distance increases. The proximity of the grow-out site to harvesting/processing facilities influences the overall risk of an operation in a similar manner.

Protocol for Estimating Risk

Decision makers implementing the outcome from a risk assessment must be able to integrate the results from the analysis into a "accept", "reject" or "modify the plan" type of response to an application for development. In doing so, they should be identifying the critical points that have led them to their decision. It is recommended that the following two step approach be taken.

Step 1. Complete the following table and provide a brief rationale with appropriate references to support the rating given.

Step 1 is a documentation of the outcome of the logic models used and must be carried out for each logic model for each risk (effect) identified in the hazard identification.

STEPS IN THE LOGIC MODEL	SEVERITY (C,H,M,L, OR N)[1]	PROBABILITY (H,M,L,EL, OR N)[2]
Step 1 of the logic model.		
Step 2 of the logic model.		
Step 3 of the logic model.		
Step 4 of the logic model.		
Etc. …….		
Final Rating [3,4]		

Explanatory notes:

1) Severity = C – Catastrophic, H – high, M – Moderate, L – Low, N – Negligible

2) Probability = H – High, M – moderate, L – Low, EL – Extremely Low, N – Negligible

3) The final rating for the Severity is assigned the value of the step with the lowest risk rating (e.g., Medium and Low estimates for the logic model steps would result in an overall Low rating). Note that the calculation of the final rating follows the multiplication rule of probabilities (i.e., the severity that a given event will occur corresponds to the product of the individual severity). Thus the final value for severity for each specific risk is assigned the value of the lowest individual logic model estimate.

4) The final rating for the Probability is assigned the value of the element with the lowest level of probability.

Step 2. The over all risk from undertaking the aquaculture activity.

The overall Risk is assigned based on the sum of **all the Individual Risks.**

COMPONENT RATING	SEVERITY (C,H,M,L, OR N)[5]	PROBABILITY (H,M,L,EL, OR N)[5]	LEVEL OF UNCERTAINTY (H, M, L)
1. Risk of Changes in primary producers Abundance (Macroalgae and Marine Angiosperms)			
1. Risk of Changes in primary producers Composition (Harmful microalgae)			
2. Risk of Changes in fitness of wild populations due to genetic intergradation			
3. Risk of Changes in macrobenthic populations			
4. Risk of Changes in trophic resources			
5. Risk of Changes in habitat (physical and chemical)			
Final risk estimate [6]			

Explanatory notes:

1) As estimated in Step 1 - Use " final rating of severity for each logic model" and "final rating for probability of achieving the results of each of the logic models", respectively.

2) As estimated in Step 2 –.Under "level of uncertainty" - the final level of uncertainty for the Final risk estimate is assigned the value of the element with the highest level of uncertainty (e.g., a High and Low ratings for the uncertainties in the probabilities would result in a final High rating).

Risk Management Components

1) Option evaluation – the process of identifying, evaluating the efficacy and feasibility of, and selecting measures to reduce the risk associated with culturing a new species in line with the level of protection appropriate to the particular jurisdiction concerned. The efficacy is the degree to which an option reduces the likelihood and/or magnitude of adverse environmental and economic consequences. Evaluating the efficacy of the options selected is an iterative process that involves

their incorporation into the risk assessment and then comparing the resulting level of risk with that considered to be acceptable. The evaluation for feasibility normally focuses on technical, operational and economic factors affecting the implementation of the risk management options.

2) Implementation – the process of following through with the risk management decision and ensuring that the risk management measures are in place.

3) Monitoring and review – the ongoing process by which the risk management measures are continuously audited to ensure that they are achieving the results intended.

The limitations of advice provided by the Working Group on the Environmental interactions of Mariculture

The above outline demonstrates that a proper risk analysis is the product of the extensive consultation and communication. A number of risk analysis for individual species are addressed in subsequent papers. The entire risk analysis process for each of the species can not be completed with the time and resources available to this Working Group. In no way should these species analyses be considered a substitute for completion of a full risk analysis prior to development of extensive industries based on the species identified below.

Instead, it is the intent of the Working Group to provide a substantive component of the historical data accumulation and organization of information that would be necessary for a proper risk analysis. Based on available information, the WG will provide what insights it can into the unique information requirement that might be necessary for the risk analysis for each of the species. Member countries should complete a full risk analysis for the conditions in their area before culturing the new species. The WG will identify those aspects to which special attention should be given for each species and, where possible, will identify areas where knowledge development would prove most valuable at improving the accuracy or reducing uncertainty in the risk analysis.

Before undertaking any risk analysis it is very important that the country undertaking the analysis define *a priori* and explicitly what is their acceptable level of protection and the benefits they are willing to forego to achieve that level of protection. Failure to do so may compromise objectivity and markedly reduce the value of the analysis.

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Annex 4: Preliminary draft of "state of knowledge" of the potential impacts of escaped aquaculture turbot

Turbot (*Psetta maxima*)

A nominative matrix for the acceptable level of risk, e.g.:

		Severity				
Probability		**C**	**H**	**M**	**L**	**N**
	H	Reject	Reject	Reject	Accept	Accept
	M	Reject	Reject	Accept	Accept	Accept
	L	Reject	Accept	Accept	Accept	Accept
	EL	Accept	Accept	Accept	Accept	Accept
	N	Accept	Accept	Accept	Accept	Accept

This is a nominative table of acceptable levels of protection (see Annex 3 for explanation). Each jurisdiction will have to construct a similar table prior to their undertaking of a risk analysis. It is expected that the table will differ between jurisdictions in accord with what is acceptable risk for that jurisdiction.

1. Hazard identification

1.1.1 Distribution

Turbot is distributed throughout the Northeast Atlantic Ocean along the European coastline and is rarer around the Faroe Islands, Iceland and on Rockall Bank. Turbot is also found in the Skagerrak, the Kattegat, the Belt Sea and in the Baltic Sea, but is very scarce in the Gulf of Bothnia, north of the Aaland archipelago, where salinity levels are below 5 psu. The distribution area also extends into the Mediterranean and Adriatic Sea. It is typically found at a depth range of 10 to 70 m. Turbot lives on sandy, rocky, or mixed bottoms and is one of the few marine fish species that inhabits brackish waters.

1.1.2 Growth and Survival

Turbot is one of the fastest growing flatfish. Only halibut grows faster. During the juvenile phase growth rates are high, through which the turbot can reach 30 cm in three years. Females grow faster than males. During the first years of life females grow from 8 to 10 cm a year. Females older than 10 years still grow 1 or 2 cm a year. In male turbot the growth is already reduced to 2 cm a year at the age of 6 years. Males older than 10 grow less than 1 cm a year. The difference in length between the sexes increases from 3 cm in 3-year-old turbot to 9 cm in 10-year-old turbot.

The maximum growth rates are obtained in 3, 4 and 5-year-old turbot during the summer (May till October). In these months growth can reach between 2 and 2.6 cm per month. This high rate is comparable with the growth in artificial circumstances. In nature the ultimate growth rate (on year basis) is lower due to the slowing-down of metabolism during winter.

Ongenae and De Clerck (1998) concluded that in general no major differences in growth could be found among the areas under study. Males and females have a similar growth rate up to age 3. Hereafter the growth rate slows down in the males while the females continue their growth at a higher rate. Asymptotic lengths (L_{∞}) varied between 47.4 cm (North Sea) and 51.5 cm

(Celtic Sea) for male turbot. For females the L_∞ ranged between 68.0 cm (eastern English Channel) and 74.4 cm (Celtic Sea). The asymptotic length thus attained highest values for both sexes in the Celtic Sea. The highest initial growth rate (characterised by the K-value) for both sexes was in the Bay of Biscay region. (Table A4.1).

Table A4.1. The von Bertalanffy growth parameters for turbot - $L(t) = L_\infty \{1-exp[-K(t-t_0)]\}$.

Location	Sex	L_∞ (cm)	K ($year^{-1}$)	t_0 (year)	Reference
North Sea	Male	55.50	0.23	−0.20	Mengi (1963)
	Female	64.10	0.23	−0.16	
	Male	49.20	0.37	−0.51	Jones (1974)
	Female	64.80	0.26	−0.05	
	Male	50.92	0.33	−1.13	Weber (1979)
	Female	68.65	0.23	−0.67	
	Male	47.4	0.44	−0.20	Ongenae and De Clerck, 1998
	Female	74.2	0.19	−0.85	
Eastern English Channel	Male	49.7	0.47	−0.04	Ongenae and De Clerck, 1998
	Female	68.0	0.26	−0.27	
Bay of Douarnenez	Male	65.20	0.32	0.09	Deniel (1990)
	Female	73.60	0.28	0.08	
Celtic Sea	Male	51.5	0.41	−0.08	Ongenae and De Clerck, 1998
	Female	74.4	0.21	−0.44	
Irish Sea	Male	49.1	0.46	−0.14	Ongenae and De Clerck, 1998
	Female	71.5	0.22	−.054	
Bay of Biscay	Male	48.5	0.56	−0.01	Ongenae and De Clerck, 1998
	Female	71.5	0.27	−0.26	
Gulf of Lion (Med)	Male	54.3	0.24	−0.22	Robert and Vianet (1988)
	Female	55.6	0.31	−0.12	
Adriatic Sea	Male	67.7	0.27	−0.86	Arneri *et al.*, 1993
	Female	81.4	0.21	−0.99	
	Male	66.2	0.31	−0.14	Arneri *et al.*, 2001
	Female	81.5	0.21	−0.48	

The growth in weight indicated differences between some areas, but they appeared to be sex-dependent. When comparing the males it became clear that North Sea turbot had the slowest growth. Bay of Biscay and eastern English Channel male turbot indicated higher initial growth rates while Celtic Sea and eastern English Channel male turbot reached the highest weights (2400 g). For the females, the highest final weights were recorded in turbot from the Celtic and North Sea (8000 g). The asymptotic weight was least for females from the eastern English Channel stock (6300 g) (Table A4.2).

Table A4.2. The von Bertalanffy growth parameters for turbot - $W = W\infty \{1-\exp[-K(t-to)]\}^b$

LOCATION	SEX	W_∞ (KG)	K (YEAR^{-1})	T_0 (YEAR)	B	REFERENCE
North Sea	Male	1.91	0.44	−0.20	2.85	Ongenae and De Clerck, 1998
	Female	8.53	0.19	−0.85	3.11	
Eastern English Channel	Male	2.43	0.47	−0.04	3.04	Ongenae and De Clerck, 1998
	Female	6.33	0.26	−0.27	3.04	
Celtic Sea	Male	2.43	0.41	−0.08	3.10	Ongenae and De Clerck, 1998
	Female	8.04	0.21	−0.44	3.18	
Irish Sea	Male	2.14	0.46	−0.14	2.87	Ongenae and De Clerck, 1998
	Female	7.29	0.22	−0.54	3.10	
Bay of Biscay	Male	2.15	0.56	−0.01	3.22	Ongenae and De Clerck, 1998
	Female	6.93	0.27	−0.26	3.15	

Overviewing the parameters of the length/weight relationships for turbot from different regions, it became apparent that the females show a higher allometric coefficient than the males, as this phenomenon occurs in almost every region. Male turbot from the English Channel and Celtic Sea has somewhat higher b-values, which means a slightly higher body weight for the same length compared to other regions. Male turbot from the Bay of Biscay have the highest allometric coeffiecient and thus the highest weight/length ratio (Table A4.3).

Tabel A4.3. Weight-length relationships ($W = a \cdot L^b$) for different areas and for each of the sexes (Ongenae and De Clerck, 1998).

Location	Sex	a	b	R^2
North Sea	Male	0.0325	2.8525	0.84
	Female	0.0133	3.1136	0.97
Eastern English Channel	Male	0.0173	3.0403	0.93
	Female	0.0168	3.0366	0.94
Celtic Sea	Male	0.0121	3.1016	0.97
	Female	0.0089	3.1845	0.98
Irish Sea	Male	0.0302	2.8714	0.96
	Female	0.0131	3.0998	0.98
Bay of Biscay	Male	0.0082	3.2182	0.94
	Female	0.0104	3.1538	0.96

1.1.3 Diet

Turbot is a typical visual feeder and feeds mainly on other bottom-living fishes (common gadoids, sand-eels, gobies, soles, dabs, dragonets, sea breams and boarfish), small pelagic fish (sprats, pilchards) and also, to a lesser extent, on larger crustaceans and bivalves. Large turbot (40 to 70 cm) feed from March till May excessive on herring and sprat (Rae and Devlin, 1972; Wetsteijn, 1981), to build up enough reserve for the subsequent spawning season. During the other nine months 50 to 70 % of the animals were found to have empty stomachs. This percentage was much higher than for most flatfish species. For example, a complete time of fasting, which is characteristic in the life cycle of lemon sole, Microstomus kitt is not observed in turbot (Rae and Devlin, 1972). The diet of the juveniles has been shown to consist of copepods, shrimps, barnacle larvae and gastropod mollusc larvae (Jones, 1973).

1.1.4 Abundance

Ongenae and De Clerck (1998) observed from the annual catches per unit effort, that the CPUEs for the North Sea and Celtic Sea with 1.0–1.2 kg/hour fishing were higher than for the English Channel, Bay of Biscay and the Irish Sea, with 0.5–0.8 kg/hour fishing.

Data from the annual Beam Trawl Surveys indicated a high abundance of turbot along the continental coast from Belgium to Denmark, with strong concentrations at the Dogger Bank and near the Wadden Sea and in the German Bight, and to a lesser extent the Scheldt estuary. In the English Channel, Celtic and Irish Sea, the overall abundance of turbot appears to be lower than in the North Sea. Other flatfish, such as sole mostly appear very abundant in the Thames estuary on the UK coast, but this was not the case for the turbot. It could be noted that turbot mainly occurred along the continental coasts of the North Sea. In the central and western part of the North Sea, turbot was much less abundant or even absent. Mainly in the central part of ICES-region Ivb, no turbot were caught. Catches by the International Bottom Trawl Surveys showed pronounced occurrence of turbot in the central parts of the North Sea and a lower abundance in the German Bight. Another remarkable difference between both survey types lies in the number of turbot caught per rectangle. These were substantially lower for the bottom trawl surveys. For these surveys, the occurrence of turbot along the east coast of the UK was observed in the years 1991–1995. This was not the case for the beam trawl surveys. Year to year comparisons for both surveys pointed out that overall abundance has decreased significantly over the years.

1.1.5. Migration

In general, turbot is rather a sedentary species, but there are some indications of migratory patterns. For example in the North Sea, migrations from the nursery grounds in the south-eastern part to the more northern areas have been recorded, since adult turbot is more tolerant of in the colder conditions in the northern areas of the Sea where temperatures are too low for juveniles to survive. A study in the northern Baltic of Aneer and Weston (1990) also indicated that adult turbot might be considered to be very stationary. In this project a large number of turbot were tagged and released. After recapture the average distance between first capture and recapture appeared to be very short: only 6 km. Furthermore, more than 90% of the recaptured turbot were caught less than 20 km away from the point of first capture.

1.1.6. Reproduction and spawning

Turbot exhibit no sexual dimorphism. The cyclical pattern of reproduction is characterised by massive gonad development and morphological changes (volume and colour), particularly of the ovaries, immediately before the emission of the gametes. In late spring to early summer, males and females gather on spawning beds, which are generally situated above gravel bottoms on the continental shelf. Fish with ripe gonads have been taken in trawls on the North Sea during the months April to July; ripe eggs have been found in the plankton from April to August (Malm, 1877; Möbius and Heincke, 1883; Brook, 1886; Ewart and Fulton, 1889; Fulton, 1892; Holt, 1892). Jones (1974) indicated the occurrence of ripe gonads between May and August. In the English Channel, the spawning season is rather long, viz. from May to September (Lahaye, 1972; Deniel, 1990). The eggs are released during the night in one batch and the fertilisation is external and at random.

The fertilised eggs are buoyant and their diameter varies between 0.9 and 1.2 mm. These eggs are extremely numerous: depending on the size of the female, their number ranges from 5 million up to 10 million per individual. The size-specific fecundity is rather constant. After spawning and feeding season, the turbot moves again to deeper waters.

First maturity for turbot in the North Sea is between ages 4 and 5 for females and age 3 for the males. This conclusion is drawn from a range of studies. Kyle (1926) determined maturity at age 6 or 7 for males as well as females. This (false) result went of course hand in hand with an incorrect age-length key. Ehrenbaum (1936) estimated first maturity at age 5 for both sexes. Length at maturity was determined by this author at 28 cm for the males and 35 cm for the females. Mengi (1963) estimated maturity at age 3, which corresponds to a length of 29–31 cm for males and 35–38 cm for females. In Rae's study (1972), maturity of the females was attained between 31 and 45 cm between the age of 4 or 5. Age of maturity for the males was set between age 3 and 4. Jones (1974) determined length, weight and age at which 50% of the females reached maturity as follows: 46.01 cm; 2001g and 4.46 years. For males a length at maturity of 30 cm was recorded. Deniel (1990) determined age and length at first maturation for the females in the English Channel at age 4 and 49 cm.

1.1.7. Further development

The fertilised eggs are carried to the shores by the currents. After more or less 7 days, the eggs hatch. At hatching, the larvae are 2.1–2.8 mm (Barnabé); 2.7–3.0 mm (Jones, 1972), 2.14–2.80 mm (Russell, 1976); 2.3–2.8 mm (Al-Maghazachi and Gibson, 1984) in length. Newly hatched turbot larvae possess a large yolk sac containing a single oil globule. This results in the larvae floating upside-down near the water surface during their first 6–12 h of life. At this time the larvae are largely inactive but may occasionally perform energetic wriggling movements. Larval growth and yolk utilisation are affected by temperature. The pelagic phase lasts around 60 days at 16°C (early summer). At the end of the larval phase the fish undergo metamorphosis, develop asymmetry, and descend to the bottom. Metamorphosis takes place at a length between 13–25 mm (NN); 23 mm (Jones, 1972); 27–39 mm (Jones *et al.*, 1974); 38–45 mm (Al-Maghazachi and Gibson, 1984); 19.8 mm (Fukuhara *et al.*, 1990). The rates at which morphological changes occur during larval development are partly under genetic control and partly reflect the influence of environmental factors such as temperature, diet and water quality.

Five major developmental stages can be recognised and are characterised as follows:

- Stage 1: Larvae symmetrical, yolk sac present.
- Stage 2: Larvae symmetrical, development of spines and air bladder.
- Stage 3: Appearance of fin rays, notochord straight.
- Stage 4: Asymmetry and eye migration, notochord posteriorly slanted dorsally.
- Stage 5: Completion of eye migration, spines and swim bladder resorbed.

There is no sharp distinction between the successive stages; in general at least half of the features characteristic of a particular stage must be developed before the onset of the next stage. For example, the right eye does not commence its migration until most of the fin rays have formed and the notochord within the caudal fin is inclined dorsally by 45° or more (Al-Maghazachi and Gibson, 1984).

The young fish that were carried by the currents towards the shore start a benthic existence. The juvenile turbot gather together on intertidal nursery grounds, where they remain throughout the summer months. In autumn they migrate from the coastal areas to deeper waters in the more Northern regions. The juvenile phase is characterised by a high growth rate.

1.1.8. Genetic structure of the populations

Only limited research on genetic stock analysis on turbot has been performed. In 1986, Renaud *et al*. (1986) showed in a study on allozymes of the cestode parasite, *Bothriocephalus gregarious*, a significant differentiation between the parasites from Atlantic and Mediterranean host turbot. The separation between these two forms was located in southern Portugal, between Lisbon and Faro. Allozyme analysis on 17 loci revealed almost no genetic differences within the complete distribution area turbot, only samples from the Aegean Sea were different from the others (Mediterranean to Kattegat), but with a negligible genetic distance as a result (Blanquer *et al*., 1992). Also Bouza *et al*., 1997 found, by the use of 14 allozyme markers a low genetic variability (P = 0.012) in both natural and hatchery populations. Imsland *et al*. (1994) did research on blood samples from turbot caught along the Norwegian coast, in Kattegat, and from the Southwest coast of Iceland. They found some genetic differentiation

(P<0.01 for Hb-1) based on haemoglobin polymorphisms between Norwegian/Icelandic turbot and turbot from the Kattegat. Studies done with three microsatellite loci on wild and farmed turbot originating from two different locations (Norway and Ireland – Celtic Sea and the Western Approaches) also revealed a lack of significant differentiation between the two wild populations (Coughlan *et al*., 1998). Which is consistent with the low level of genetic differentiation found in the allozyme studies (Blanquer *et al*., 1992; Bouza *et al*., 1997). However, Coughlan *et al*. (1998) stressed the importance of further genetic analysis with more microsatellite loci to screen wild turbot across its distribution area. Bouza *et al*., 2002 found, employing 12 microsatellite and 28 allozyme loci, no differentiation between turbot from the Atlantic Ocean (Burela – 43°40'N, 7°22'W) and the Cantabric Sea area (Vilagarcia – 42°36'N, 8°45'W), areas which are separated by a major oceanographic discontinuity (Harden Jones, 1968). Recent studies carried out by Nielsen *et al.* (2004) on turbot from the Northeast Atlantic and the Baltic Sea (from the Bay of Biscay to the Aaland archipelago) suggests that the presence of multiple hybrid zones in the transition zone (Skagerrak, Kattegat and Belt Sea) between the high saline North Sea and the low saline Baltic Sea. The differentiation between turbot from the North Sea and the Baltic Sea was also observed by Karås and Klingsheim (1997) based on the effects of temperature and salinity on embryonic development of turbot from the two areas. Further research on population structure in the distribution area of turbot was undertaken by Boon *et al*. (2000). The preliminary study showed, using four microsatellites, that turbot from the English Channel appears genetically indistinguishable from the Bay of Biscay. Also turbot from the North Sea was not indistinguishable from the Celtic Sea. While turbot from the Irish Sea appeared to be genetically different from turbot from all other areas under research (Table A4.4).

Table A4.4. Matrix of genetic distance (DA) estimates above the diagonal and P-values below the diagonal, between turbot from different fishing grounds (Boon *et al.*, 2000).

	North Sea	English Channel	Celtic Sea	Irish Sea	Bay of Biscay
North Sea	-	0.169	0.151	0.220	0.171
English Channel	0.052	-	0.196	0.220	0.120
Celtic Sea	0.111	0.005	-	0.235	0.208
Irish Sea	0.002	0.000	0.000	-	0.195
Bay of Biscay	0.019	0.367	0.002	0.001	-

Although samples sizes were small (20 samples per area) and these estimates must be considered as very preliminary, it appears likely according from the results of the statistical analysis that there exists a turbot population in the Irish Sea, which would be genetically different from the other areas under research. This was also noticed by Ongenae and De Clerk (1998) analysing the fishing and landing parameters. There was also a difference found (although not so significant) between turbot from the Celtic Sea and the North Sea, and turbot from the English Channel and the Bay of Biscay. The low genetic differentiation between the North Sea/Celtic Sea and English Channel/Bay of Biscay is caused by the low genetic differentiation between the samples from the English Channel and those from the North Sea. This could mean that the English Channel acts as a transition zone between the Bay of Biscay and the North Sea. Tagging experiments on several flatfish species (turbot, plaice, dab and sole) indicated migrations of small portions from the North Sea into the English Channel (De Clerck and Cloet, 1975; De Clerck, 1984; Delbare and De Clerck, 2000). A similar transition or hybrid zone was found between the North Sea and the Baltic (Nielsen *et al*., 2004) (Figure A4.1).

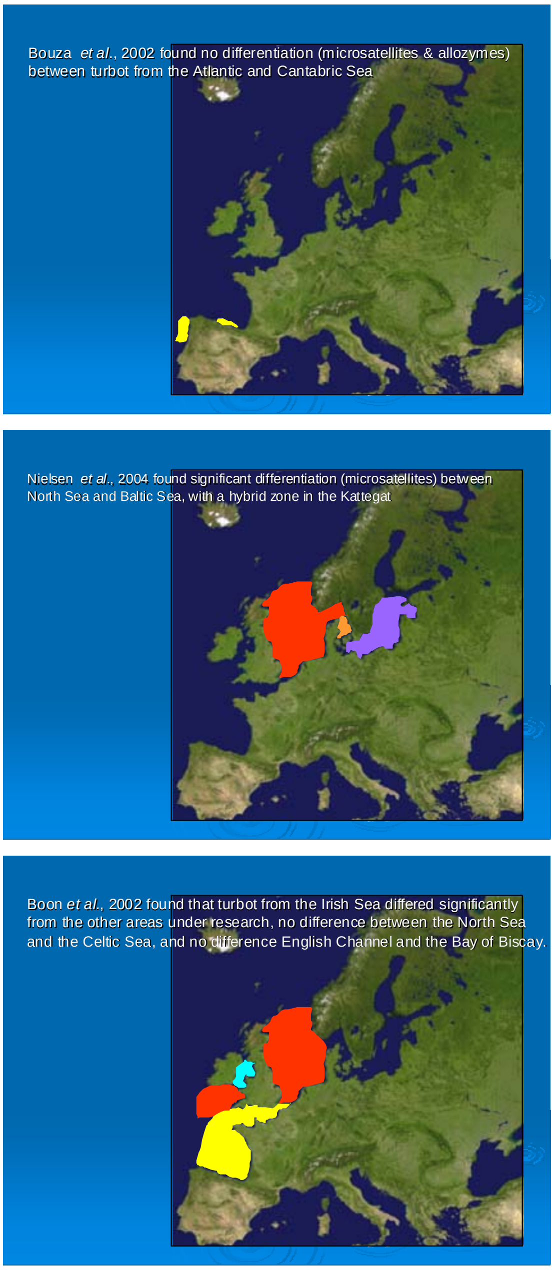

Figure A4.1. Areas which were studied and showed genetic differentiation.

Compiling all data from different studies, it becomes clear that there are distinct turbot populations in the Baltic Sea and in the Irish Sea. Furthermore there are indications that turbot from the North Sea, the southern coast of Iceland, the western coast of Scotland and Ireland, and the Celtic Sea (including the Western Approaches - 51°N, 10°W) forms another stock, the northern Atlantic stock, which is different from the stock originating from the Bay of Biscay and the Atlantic site of southern Europe, the southern stock. Transition zones between the northern stock and the southern stock is found in the English Channel and between the northern stock and the Baltic Sea in Kattegat and the Belt Sea. The situation of turbot stocks in the Mediterranean is still unclear, although there are indications that samples from the Aegean Sea are genetic different from those originating from other areas (Figure A4.2).

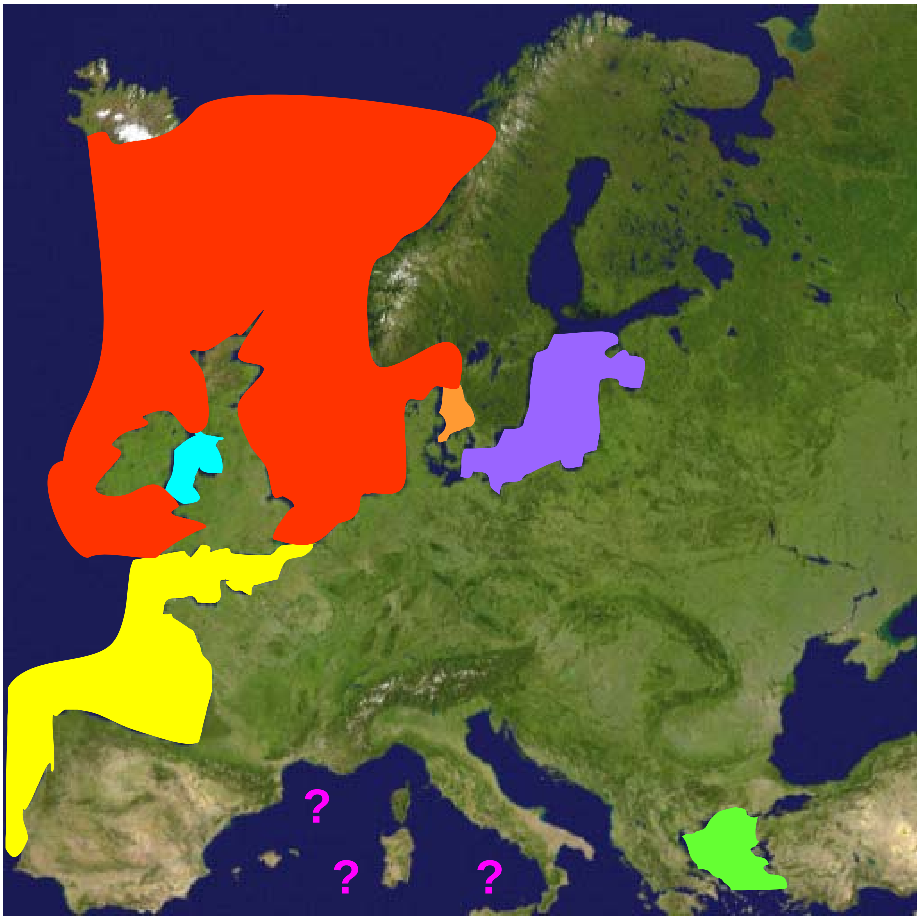

Figure A4.2. Preliminary map of the population structure of turbot.

1.2. Known effects of cultured populations

1.2.1. Genetic variability in broodstock

Only limited evidence exists for reduced variability in farmed strains of turbot, as was described for other cultivated fish species (Cross and King, 1983; Verspoor, 1988). Bouza *et al.* (1997) observed a reduction in heterozygosity in farmed strains of turbot in comparison with wild populations taken of the Norwegian coast and the Celtic Sea. This was also noticed by Coughlan *et al.* (1998) for farmed turbot from Norway and Ireland. Bouza *et al.* (2002) observed lower allozyme heterozygosity and loss of genetic variation in comparison with samples from the wild. The decrease in differentiation and divergence found in the farmed strains was believed to be caused by genetic drift during culture, due to the use of a limited number of broodstock animals. These results, however, can not be generalized, since broodstocks from other turbot farms in Galicia (Bouza, unpublished data) and France (Estoupe *et al.,* 1998) show much higher genetic diversity values, which were not different from the wild stocks.

Imsland and Jonassen (2001) observed that turbot was sensitive to the length of the light period, with longer light periods showing enhanced growth. But authors also revealed that growth in some cases was enhanced at lower temperatures and longer day lengths. Usually, warmer temperatures enhance growth. They concluded that a strong genotype by environmental interaction must be present.

1.2.2. Behaviour in the wild of released turbot

In the past, introductions of turbot have been carried out in the former USSR (1930) (FAO, 1997), in Iran (period 1930–1931) (Coad, 1995), and in Chili for aquaculture purposes (FAO, 1997, Pérez *et al*., 2003), but with no successful recapture or establishment of breeding populations. Turbot, however, was successfully introduced (self reproducing) into waters around New Zealand (Muus and Nielsen, 1999). Experimental releases of cultured fry for stock enhancement purposes have been performed in Spain (Iglesias and Rodriguez-Ojea, 1994), Denmark (Nicolajsen, 1993; Støttrup and Paulsen, 1998), and Norway (Bergstad and Folkvord, 1998).

The Sea Fisheries Department in Belgium has started to investigate the possibilities of restocking commercial important North Sea flatfish species, e.g., turbot and sole (*Solea solea*). Turbot was chosen as the first candidate, as reproductive biology and rearing techniques for all life stages are fully understood and under control. Delbare and De Clerck (2000) obtained 3000 juveniles from a commercial fish farm: France Turbot – Adrien Group (Noirmoutier, France) and reared for another 6 months in the pilot nursery system of the Department Sea Fisheries – CLO (Ostend, Belgium). Before release, the juveniles were conditioned for two months to natural live prey organisms, e.g. brown shrimp (*Crangon crangon* L.) and sand gobies (*Pomatoschistus* sp.). Next to that, all juveniles were tagged with a Petersen disk (Petersen, 1893). The tagged turbot were released in a for fisheries closed area (release position: 51°12’000 N and 02°45’600 E). Approximately 16% of the released turbot was reported back after a period of 1.5 years. At the end of 2004 more than 30% of the released turbot was reported. The migration pattern of the released turbot juveniles is presented in Figure A4.3. During the first two months after release, the juveniles remained in Belgian coastal waters following the main current towards the Dutch coast. The direction in the two following months (August–September’98) was clearly north – north-east, with the centre of capture on the Flemish sand banks. The same situation was found in October–November’98, although a portion of the animals was migrating into deeper water, i.e. the central part of the Southern North Sea. In the months December’98–January’99 some of the turbot were captured in the proximity of the “Thornton Bank”, while most migrated into deeper waters. Such an off-shore migration pattern, from shallow water during late spring and summer into deeper water during autumn and winter was also observed by Bagge (1987) for turbot in the Kattegat. In February–March’99, the major part of tagged turbot was still captured in deeper waters, with some found in more coastal waters (the Netherlands and the United Kingdom), but also into the Dover Straits, in the proximity of Bologne sûr Mer (France) and Port Rey (United Kingdom). This situation continued in the periods April–May’99, June–July’99 and August–September ’99. However, in the latter period, a concentration of turbot was seen again in the area around the “Thornton Bank”. Further captures (more than 30% of the released juveniles) were found scattered throughout the southern en central North Sea and the English Channel.

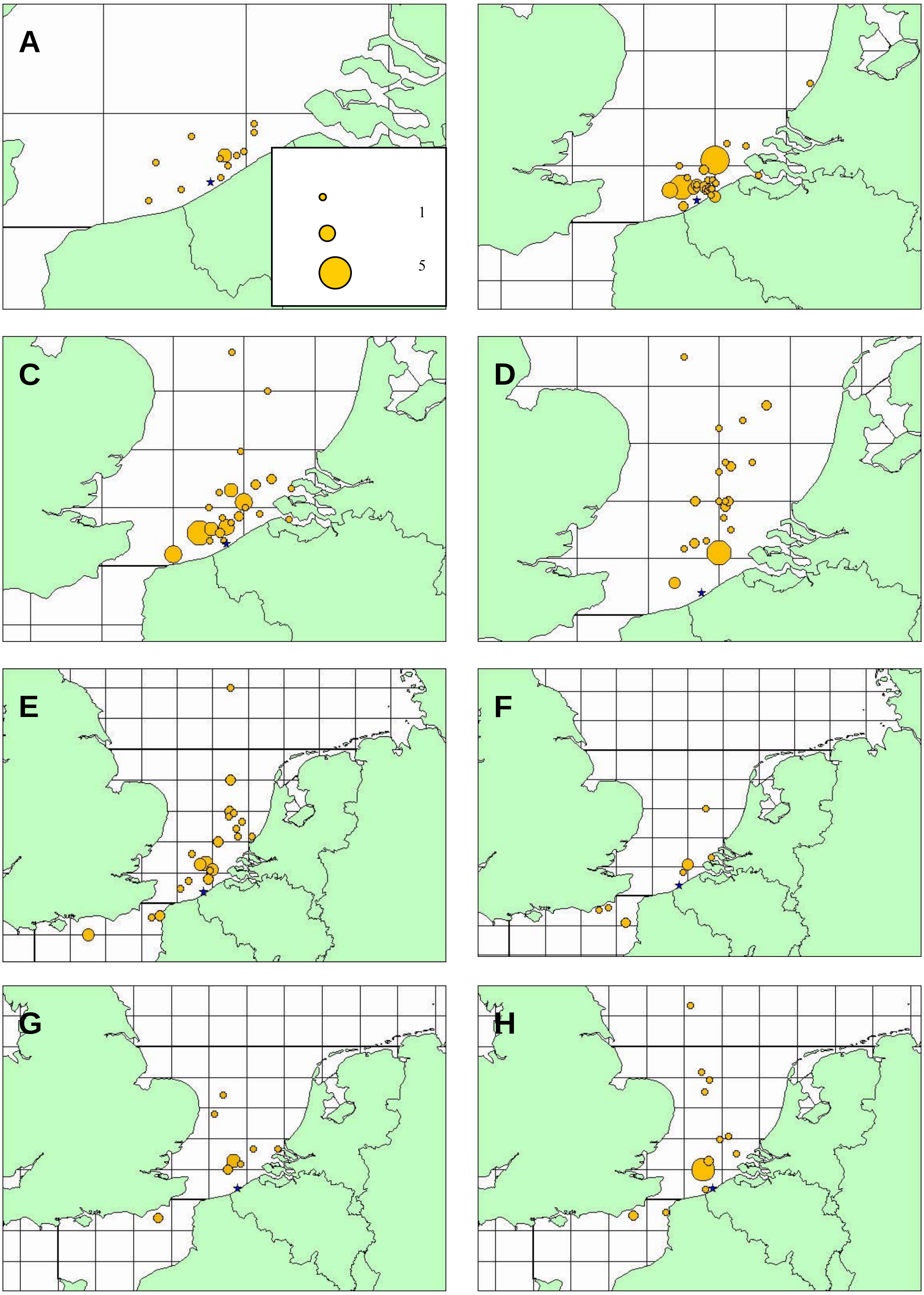

Figure 3. Distribution of the released turbot in time : A. June-July'98 ; B. August-September '98 ; C. October-November ; D. December '98-January '99; E. February–March '99 ; F. April–May '99 ; G. June-July '99 ; and H. August-September '99.

The general migration pattern of the released juvenile turbot followed a north – north-west direction into deeper waters of the North Sea, but with a migration to more coastal waters in late spring and summer. Only a small portion migrated in south - south-western direction into the English Channel. Migration in northern direction started from October 1998 onwards, while tagged turbot in the English Channel were reported from February 1999 onwards. In tagging experiments with other flatfish species (plaice, dab and sole), it was also observed that a small portion migrated from the North Sea into the English Channel (De Clerck and Cloet, 1975; De Clerck, 1984). Growth rate was similar in comparison with the turbot in the wild, although these animals were initially bigger due to the high culture temperatures and *ad libitum* feeding. Other studies on released turbot revealed no differences in growth rate with their wild counterparts (Støttrup and Paulsen, 1998; Støttrup *et al*., 1998a and b). The stomach analyses showed that the released turbot were able to adapt to the natural food sources. Turbot of the length class 21–23.9 cm fed exclusively on gobies (*Pomatoschistus* sp.). With increasing length, there is a change in prey spectrum, in which other bottom dwelling fish (e.g. lesser weever, *Trachinus vipera* and dragonet, *Callionymus* sp.) and brown shrimp (*Crangon crangon*) were eaten. From 30 cm onwards a significant change in feeding habit occurs, raging from consumption of benthic organisms to hunting for pelagic fish, e.g. bib, *Trisopterus luscus.* The monthly variation in condition factor showed that the animals well adapted to the natural conditions, with a condition factor between 1.8 and 2.2, which was comparable with the range in wild turbot populations (Ongenae and De Clerck, 1998). Furthermore, no major differences in condition factor was noticed between released and wild turbot in the research period.

Several restocking experiments with turbot showed that survival rate of reared turbot in the wild was very high. Survival can, however, be further enhanced by conditioning the reared juveniles to natural conditions. Reared turbot were found to exhibit lower cryptic behavior compared to their wild counterparts. After conditioning the reared animals to a sand bottom, the juveniles exhibited an improved cryptic behaviour and a more efficient burying technique (Støttrup and Nielsen, 1998). Stomach analyses on newly released turbot showed within two months after release lower stomach weights than wild fish of the same size. However, conditioning reared turbot to natural food increased the feeding success after release in the wild (Støttrup and Paulsen, 1998). Studies undertaken to estimate the carrying capacity of habitats along the European coastline revealed that the carrying capacity is rarely reached (van der Veer et al., 1990; van der Veer et al., 1991; Rijnsdorp et al., 1992; Henderson and Seaby, 1994) and could therefore sustain small quantities of released or escaped fish.

1.2.3. Effect of interbreeding between wild and escaped/released fish

At present no studies have been carried out on the interactions between wild and reared turbot. But for other species extensive data on interbreeding between escaped and wild individuals are available.

Among the main concerns is the loss of genetic variability within and among populations, with a reduction in flexibility to respond to environmental changes. This becomes a serious problem when the genetic variation within a hatchery population is reduced due to inbreeding, selective breeding, or domestication. Even one generation of artificial spawning and hatchery rearing can cause shifts in the genetic make-up (genetic variability and composition), with often detrimental effects to fitness (Allendorf and Ryman, 1987; Cross, 1999).

Interbreeding between wild and escaped domesticated salmon has been observed by Crozier (1993), Webb *et al.* (1993) and Clifford *et al.* (1998). Carr *et al.* (1997) and Saegrov *et al.* (1997) even noticed that in some cases the majority of the fry production in a population was produced by escaped cultured females. Other studies show that for salmon in certain Scottish rivers at least 7% of the spawnings are attributed to farmed female salmon (OSPAR QSR, 2000). Studies with Atlantic salmon demonstrated a significant superior survival of wild strains compared to farmed and hybrid strains under the same natural stream conditions, which means that there is a reduced fitness of the progeny from interbreeding. Fleming and Einum (1997) reported that farming of Atlantic salmon generated rapid genetic change that altered important fitness-related traits relating to behaviour and growth. Skaala *et al.* (1996) reported that survival of young juveniles was nearly three times higher in wild brown trout than in hybrids of wild and introduced (and genetically distinct) trout. Reisenbichler and Rubin (1999) reviewed a number of studies on Pacific salmon and concluded that they provide strong evidence that fitness for natural spawning and rearing can be rapidly and substantially reduced by interbreeding between wild salmon and those produced by artificial propagation.

A difficulty with demonstrating outbreeding depression is that the severity of the action becomes evident in the second and subsequent generation hybrids. Only few studies have continued to monitor the interactions over longer time periods, e.g. Jorstad *et al.* (1994) with cod *Gadus morhua*, and McGinnity *et al.* (1997) with Atlantic salmon *Salmo salar*. Perez-Enriquez *et al.* (2001) studied the genetic diversity of red sea bream (*Pagrus major*) in western Japan, in order to investigate the effects of stock enhancement programs around Shikoku Island on the genetic differentiation among wild stocks. They found significant departures from Hardy-Weinberg equilibrium and significant pairwise F_{st} among locations, that indicated genetic instability within this region. It was suggested that stock enhacement caused this genetic instability. For Pacific salmon, Reisenbichler and Rubin (1999) also observed genetic changes from stock enhancement, which affected the productivity and viability in wild stocks. The effect of interbreeding between wild and cultured could cause catastrophic results to wild population in the long run. High numbers of escapees that interbreed with small populations, like in salmonoids, can cause genetic incompatibilities between parents, that does only occurs in the second generation, when recombination of the parental genes takes place (Smoker *et al.*, 2004). This, however, provides the possibility of increased hybrid formation until the second generation.

2. Risk Assessment

The specific risk under examination in this section is the consequences of releases (accidental or intentional) of cultured fishes on Fitness of Wild Populations of turbot due to Genetic Intergradation.

<u>Our evaluation is based on the following set of conditions leading to the expression of a</u> significant decline in survival in wild turbot populations is likely due to interbreeding with escaped cultured turbot, e.g.,

1) Some turbot will escape captivity and,
2) will interact with wild stock by interbreeding and,
3) there will be significant differences between composition of the will and cultured stock, and,
4) those differences are such that the cultured population genome would be less well adapted to survival in the wild, and
5) the intergradation event will rapidly effect a large portion of the wild stock in question and,
6) hybrid cultured wild fish would lower survival of the fish population below the level to which the cultured fish enhance the number of fish in the population and,
7) the occurrence of intergradation will be repeated every year and,
8) the duration of the depression in survival is likely to last for a number of generations after cessation of escapes

2.1. Release Assessment

2.1.1. Turbot in aquaculture

Turbot culture has developed rapidly in the last two decades, growing from 4 mt in 1984 to 6748 mt in 2003 in Europe. In China production is estimated at 3000 mt (approximately 33% of total turbot production) and 350 mt in Chile (approximately 4% of total turbot production). The majority of production systems for turbot are land-based recirculation systems for juveniles and ongrowing (Figure A4.4). Tank volumes can differ according to the farm and depends on the holding system in use. For example, small water volumes are used in “shallow raceway” systems or very high volumes of 3600 m³ in Puraq`s Sunfish aquaculture (Cambados, Galicia). Maximum stocking densities are presented in Table A4.5.

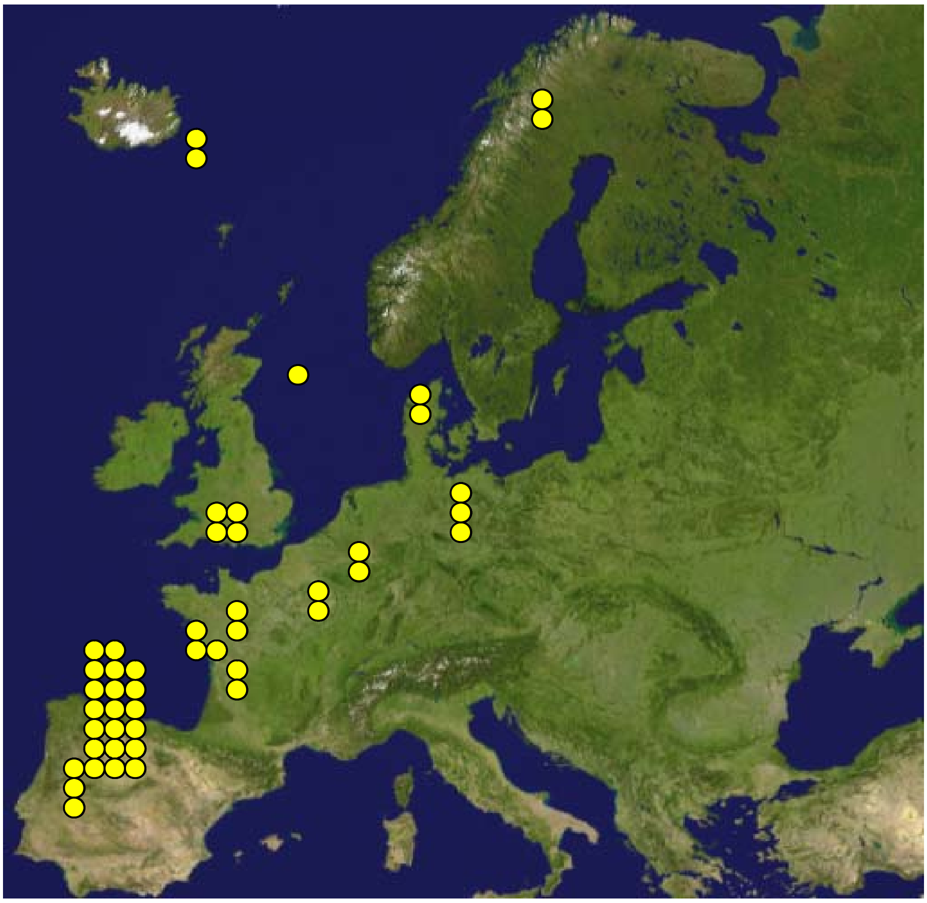

Figure A4.4. Turbot production sites in Europe.

Table A4.5. Maximum stocking densities (kg.m^{-2}) for turbot (Cachelou, 1992; Kamstra, 1992).

START WEIGHT OF THE FISH (G)	END WEIGHT OF THE FISH (G)										
	1	5	10	40	75	125	300	600	1000	2000	5000
1		5	5	5	5	5	5	5	5	5	5
5			5	5	5	5	5	5	5	5	5
10				10	10	10	10	10	10	10	10
40					20	20	20	20	20	20	20
75						20	20	20	20	20	20
125							30	30	30	30	30
300								40	40	40	40
600									50	50	50
1000										60	60
2000											60

No information is available on the actual number of escaped fish from the turbot farms.

2.2. Exposure Assessment

Turbot is a widespread species (from Morocco to Norway and into the Mediterranean Sea), but only in low abundances. Total annual turbot production equals the total landing (approximately 7000 mt) of this species, but is concentrated in only a few areas. This means that an accidental release could mean a very sharp increase in turbot numbers in one area.

From a study carried out on turbot by Boon *et al*. (2000) the turbot population size in the North Sea for the period 1981–1989 was estimated at approximately 11000000 individuals. In 1990, however, there was a strong recruitment estimated at 60000000 one year old turbot with a total stock number of 68000000 individuals. The mean CPUE for the North Sea increased after 1990 (Ongenae and De Clerck, 1998).

Taken into account that almost 75% from European turbot landings originates from the North Sea and the CPUE data from the Beam Trawl Survey showing for the English Channel, the Celtic Sea and the Irish Sea rarely 5 ind. per hour fishing in certain ICES rectangles, total stock numbers must be much lower in these areas than in the North Sea and are somewhere in the range of:

- 1,000,000 individuals for the eastern English Channel (0.7 kg per hour fishing)
- 660,000 individuals for the Celtic Sea (1.0 kg per hour fishing)
- 275,000 individuals for the Irish Sea (0.6 kg per hour fishing)
- 770,000 individuals for the Bay of Biscay
- No estimation available for stock numbers for the Atlantic coast of the Iberian peninsula or the Mediterranean Sea.

Note of caution: these numbers are very crude approximations with considerable uncertainty but could reasonably be expected to be within 3 orders of magnitude.

No studies have been carried out on the interactions between wild and reared turbot, but interbreeding is most likely when the escaped/released turbot have matured, although it is not certain if these turbot have the sensory clues to migrate to spawning areas.

Turbot is a predator high on the trophic pyramid and release experiments have shown that reared turbot juveniles are very successful in adapting to conditions in the wild and have no problem in finding prey items (Støttrup and Paulsen, 1998, Støttrup et al., 1998a; Delbare and De Clerck, 2000). The natural predator avoidance strategy in flatfishes is to flee to the bottom, bury into the sediment and remain motionless. It is expected that such cryptic behaviour is not as effective in reared fish than in their wild counterparts, since turbot is cultured in bare bottom tanks. In some cases even lengthy off-bottom behaviour is displayed by cultured Japanese flounder (Tsukamoto *et al.*, 1997). Reared turbot were found to exhibit lower cryptic behavior compared to their wild counterparts. Avoidance of predators through burying in the sand is lower in reared turbot than for their wild counterparts. After conditioning to sandy bottoms, cryptic behaviour can be improved significantly (Støttrup and Nielsen, 1998). Conditioning is only carried out prior to controlled release in the wild. According to Iglesias and Rodriguez-Ojea (1994), however, cultured turbot buried immediately in the sand upon release in their stock enhancement experiments.

Studies on released turbot in the North Sea showed that juveniles dispersed through the North Sea and for a lesser portion moving into the English Channel. Off-shore migration was seen during autumn and winter, while near-shore migration took place in spring and summer. Similar migration patterns of turbot were observed by Bagge (1987) for wild turbot in the Kattegat.

2.3. Consequence Assessment

2.3.1. Establishment of turbot farms

Turbot farming is a well established mariculture activity in Europe and growth in production is still foreseen in the near future.

Conclusion: Many farms are active in turbot production

2.3.2. Differences between the genome of wild and cultured turbot

In many turbot farms it is the practice to use wild-caught mature adults as broodstock (Bouza, unpublished data; Estoupe *et al.*, 1998). There is however evidence that more and more turbot farmers are selecting juveniles with high growth rates and less malpigmentation, in order to increase production outputs. Furthermore, several turbot farmers are obtaining fish from a select few hatcheries. For turbot, some evidence of lower allozyme heterozygosity and loss of genetic variability exists in farmed strains of turbot (Bouza *et al.*, 1997; Coughlan *et al.*, 1998; Bouza *et al.,* 2002).

Conclusion: Genetic differences have been observed between wild and cultured turbot.

2.3.3. Turbot escapees

Although turbot is mainly cultured in land based systems on recirculation, escapes are possible through outlets in flow through systems (when used) or by getting into dewatering channels by accident during sorting and handling of turbot and taken to the sea. Further impact on wild stocks could be expected through accidental release of fertilized eggs in the environment, since most incubation tanks are run in an open flow through system. The risk on escape will increase when culture systems are changed from on-land based systems to sea cage culture. In the latter, it is more likely that escapes could form a significant route for genetic interaction with the wild stock. Net cages can be damaged due to heavy weather conditions (storms), persistent predators such as seals that try to get at the fish, industrial accidents (human error or equipment malfunction), and even vandalism. So far, no information is available on the actual number of escaped fish from land based turbot farms, but the number is likely to be very small. However, with the use of sea cages for turbot, the risk on escapes could increase substantially, since accidents do happen. But it is predicted that the losses in net cage culture would be much lower than, for example the 20–25 incidents per year reported from 1998–2003 in salmon net pen aquaculture in Scotland (the escape rate is estimated at 0.1–1.0% of the stocked smolt; I.M. Davies, pers. Comm).

Conclusion: escaped turbot from land based farms is likely, but in very small numbers, especially in land based flow through systems and during sorting and handling. The risk becomes much higher for net cage cultured turbot.

2.3.4. Interbreeding

Although there have been no studies carried out on the interactions between wild and reared turbot, interbreeding is most likely when escaped turbot have matured, Studies of released juvenile turbot in the wild have shown to exhibit only small differences in feeding and cryptic behaviour (for a short period after release). Migratory patterns of released turbot showed a similar off-shore migration during autumn and winter, and a near-shore migration in spring and summer, as seen in wild turbot (Bagge, 1987). But it is not certain that escaped turbot have the necessary sensory clues to migrate to spawning areas.

As a precautionary approach, one can look to other examples of interactions between reared and wild fish. In Atlantic salmon there is clear evidence of interbreeding between wild and escaped domesticated individuals.

Conclusion: evidence for interbreeding in turbot is not given but is known in other species, for example, Atlantic salmon.

2.3.5. Reduced fitness caused by interbreeding

There exists no evidence for a reduced fitness caused by interbreeding between wild and cultured turbot. As a precautionary approach, one can look to other examples of interactions between reared and wild fish. In brown trout, Pacific and Atlantic salmon, there is clear evidence of reduced fitness of the progeny from interbreeding.

Conclusion: there is no evidence for reduced fitness by interbreeding in turbot, but there reduction of fitness was observed in salmonids.

2.3.6. Risk on affecting population fitness

The knowledge about the population structure throughout the distribution area of turbot is still incomplete. Currently, the situation in the northwestern part of the Atlantic Ocean is that there are two distinct populations in the Baltic Sea and in the Irish Sea. Furthermore, there are indications that there is a northern (sub)population (North Sea/Celtic Sea, including the Western Approaches - 51°N, 10°W) and a southern (sub)population (English Channel/Bay of Biscay/Atlantic coast of Spain). Between the northern (sub)population and the Baltic population there is a transition zone, situated in Kattegat and the Belt Sea, and a second between the northern and southern (sub)population in the English Channel. Turbot is a wide spread species (from Morocco to Norway and into the Mediterranean Sea), but is found in low abundances. These abundances have decreased significantly over the last years. However, with the reduction in TAC of sole and plaice, in order to protect certain sole and plaice stocks, but also cod in general, fisheries mortality of the wild stocks will decrease, as turbot is a bycatch product of beam trawling on sole and plaice. It is expected that accidental escapes of small numbers of reared turbot have a limited negative impact on wild populations, but could be substantial in areas with explicit stock characteristics, e.g. the Baltic and the Irish Sea.

Conclusion: wild populations with a limited distribution area and under high fishing pressure can be affected by interbreeding.

2.3.7. Decline in survival in wild turbot populations

There is no evidence to support this contention for turbot. As a precautionary approach, one can look to other examples and in Pacific salmon lower productivity and viability in wild stocks were observed after inbreeding with domesticated salmon.

Conclusion: there is no evidence in turbot for a loss in fitness after interbreeding, but reduction in productivity and viability in offspring was observed in Pacific salmon.

2.3.8. Escapes of farmed turbot cause significant decreases in wild/feral turbot stocks

There is no evidence to support this contention for turbot. As a precautionary approach, one can look to other examples and in salmon indications were found that interbreeding between wild and cultured could cause catastrophic results to wild populations.

Conclusion: there is no evidence in turbot for decrease in wild stocks due to interbreeding, but genetic changes leading to reduced survival in the wild is a feature of all domesticated salmon and consequently in hybrids from farmed and wild fish.

3. Risk evaluation

Risk evaluation based on a set of conditions (see above) leading to the expression of a significant decline in survival in wild turbot populations is likely due to interbreeding with escaped cultured turbot (Table A4.6).

Table A4.6. Risk evaluation for interbreeding between escaped cultured and wild turbot.

	SEVERITY	PROBABILITY	UNCERTAINTY
1. Establishment of turbot farms	N	H	N
2. Differences between the genome of wild and cultured turbot	N	H	L
3. Turbot escapees	L	EL	M
4. Interbreeding	M	EL	M
5. Reduced fitness caused by interbreeding	M	EL	H
6. Risk on affecting population fitness	H	N	H
7. Decline in survival in wild turbot populations	H	N	H
8. Escapes of farmed turbot cause significant decreases in wild/feral turbot stocks	C	N	H

Severity: C-Catastrophic, H-High, M-Moderate, L-Low, EL-Extremely low, N-Negligible

Catastrophic: The occurrence of a risk that would be expected to cause serious irreversible harm to ecosystem performance at the faunal level

High: The expression of a risk that would have serious biological consequences

Moderate: The change that has a less protrated biological consequence.

Low: The expression of a risk has mild consequences and would be amendable to control or mitigate.

Negligible: The measurable changes are not significant at a ecosystem level and are readily amendable to control or mitigation.

Probability: H-High, M-Moderate, L-Low, EL-Extremely low, N-Negligible

High: There is high probability that the event will take place

Moderate: There is a reasonable probability that the event will take place

Low: There is a chance that the event could take place

Negligible: Chances are rare that the event will take place

Uncertainty: H-High, M-Moderate, L-Low, N-Negligible

High: The chance of the risk being expressed is so small that it can be ignored

Moderate: There is reasonable uncertainty as to whether the risk will be expressed

Low: The risk is more likely than not to be expressed

Negligible: the event is very likely

4. Effect of Infrastructure on Risk

4.1. Regulation

- There is some indication that there exists several (sub)populations, which probably have there own optimal growth temperature and salinity range, especially for the Baltic and the Irish Sea. However, it is advisable to use as broodstock animals from those stocks that are best fitted for that specific culture location. Decrease in genetic differentiation and divergence was found in the farmed strains, therefore special breeding programs must be set up to guarantee a high level in heterzygosity in farmed strains. Furthermore, it is important to use broodstock animals for restocking that are related to the local turbot (sub)population, in order to minimize adverse genetic interactions with the wild stock..

- The use of triploid turbot would reduce the risk of interactions with the wild stock. Experiments with hybrids between turbot and brill have been carried out to produce only female offspring (Purdom and Thacker, 1980).
- To limit escapees, physical barriers must be installed in all outlets of open flow through systems. Double mesh screens must be installed in the outlet of broodstocks at all times, toe prevent fertilized egg loss. Closed recirculation techniques can further reduce the risks of escapes.
- Particular attention should be paid to robust containment technologies for sea cages, when cage culture of turbot would become feasible.

4.2. Code of practice – certification

- In all cases, the training of operators should be an essential preoccupation by the fish farmer. The maintenance and cleaning of tanks, and in case of cage culture the replacement and monitoring of nets is of the outmost importance to limit accidental escapes. Periodic inspection of tanks (outlets and physical barriers) and nets, should be compulsory. Special attention should be paid to the procedures of sorting and treatment operations.
- At present, declaration of turbot escapees is not compulsory in any country. To reduce uncertainty, the need for regulatory enforcement, and improved mandatory reporting should be introduced. Since there is no additional cost inferred to it, it would be profitable to both the industry and the environment. In Ireland salmonid farmers is obliged immediately following any escape of reared salmonids from a freshwater or marine installation, to fill out a *Reared Fish Escapees — Incident Report Form* and contact the Department of Communications, Marine and Natural Resources (DCMNR), Marine Institute and relevant Regional Fisheries Board(s). The operator is required to report the number of escapees and cause of the escape, if known. The DCMNR collates this information with a view to making recommendations to try and prevent other incidences from happening. Nevertheless, there are no accurate data available for the number of escapes in Ireland. Voluntary Codes concerning escapes: aquaculture industry self-regulation and environmental safeguards through voluntary Codes are effectively worthless forms of governance in the absence of binding legal obligations to enforce rules (See Regulation of Marine Aquaculture). Concerning stock health management, it is a recommended action under the Code to implement the Irish Salmon Growers' Association (ISGA) Code of Practice for the prevention of stock escapes of Irish farmed salmonids (reproduced in Annex III of ECOPACT). The ECOPACT document also annexes the Federation of European Aquaculture Producers (FEAP) Code of Conduct for European Aquaculture.
- EU policy on escapes: in its Communication A strategy for the sustainable development of European aquaculture (COM(2002) 511 final, 19/9/02) the European Commission states that 'escaped fish inter-breeding with native populations may induce long-term damage by the loss of genetic diversity'. The Commission proposes developing instruments to tackle the impact of escapees as part of the EU Aquaculture Strategy and states that it 'has financed research on the threats to the diversity of wild Atlantic salmon caused by farm escapees, but further studies are needed. The process started in February 2000 by NASCO and the North Atlantic salmon farming industry to develop guidelines to minimise salmon escapees is particularly worthy of support. The Commission will examine whether such guidelines should be implemented by way of compulsory rules and may extend them to other fish species and strains.'

5. Risk Management

Identify a list of options for controlling risk e.g.

a Keep all culture on land

Some experiments have been carried out in Scotland for cage culture turbot, but with limited success. Recirculation techniques are improved to be able to culture turbot on full recirculation in order to enhance the control and reduce the dependence on natural water resources and heating costs. Nowadays, most of the turbot is farmed at 75–80% recirculation. It is expected that in the next five years all turbot are farmed at 100% recirculation. The severity on escapees and probability would be reduced and subsequently the interaction between wild and farmed turbot. With land based culture of turbot on full recirculation, the uncertainty of escapes would be negligible

b Use sterile fish

Manipulation of sex and ploidy are being introduced in fish farming. All-female production is economically advantageous, because in many species female growth rate is higher compared to that of the males and first maturation takes place at older age. The market value declines drastically with maturity. For example, all female rainbow trout *Oncorhynchus mykiss* are cultured in Europe (Ingram, 1988) in order to reach greater market size before maturing. Tests with hybrids have been carried out with brill, *Scophthalmus rhombus*. These hybrids showed a higher survival rate during larval development and metamorphosis. Hybrids between these two species can also been found in nature. Holt (1892) noted three hybrids caught in the North Sea differed significantly from turbot or brill in body form, color, scale and number of fin rays. Hybrids formed between a female turbot and a male brill, were all females and could reach a weight of 382 g at natural temperatures. While hybrids formed between a male turbot and a female brill resulted in a all male stock and grew to 289 g in 20 months at the same temperatures (Purdom and Thacker, 1980). Successful experiments to obtain an all-female stock were carried out in the UK and are interesting for the farmer since they exhibit a 12% high growth rate and only rudimentary development of the ovaries. In turbot females, ovaries can take up 15% of the total body weight (Bye, 1981) as gonad development can divert much energy from somatic growth. Induced triploidy is also used to produce sterile fish, which continue to grow somatically (Ingram, 1988). The severity on interaction between a wild and all-female turbot would remain the same, but the probability would be reduced to extremely low to negligible. The uncertainty would be extremely low to negligible. In Europe experiments with trout and turbot (Vázquez *et al.* 1996; Cunado *et al*., 2002; Terrones *et al*., 2004.) have been carried out, although for turbot this technique is not used in commercial farms.

c Create dependence on specific food supplements that are not redily available in the wild

Another possible technique is to produce genetically modified turbot, that are incapable to synthesize certain nutritional components and which are not available in nature. Reared turbot would therefore be totally relying on the artificial diets given in captivity providing these essential nutrients. Once a fish has escaped from the rearing system, it could not survive in the wild due to deficiency. This technique would reduce the severity of escapes. The probability that the escapee would find food containing the essential nutrients depends on the chosen component, but would be very low. The uncertainty could be low to moderate, taken into account that one have a very good knowledge about the natural prey items. This feeding technique is still highly hypothetic and needs substantial theoretical developments (animal welfare, technical feasibility, GMO regulations, human welfare, etc.).

d Contingency Planning

The degree of monitoring all activities on the farm must be in function of the degree of risk in relation to the farming system. In this respect there is a decreasing need for intensive control from sea ranching to inshore sea cages, flow through land based systems to closed recirculation culture systems.

Recovering large number of escapees in a certain area could be carried out by using gill nets in the area shortly after the accident has occurred.

5.1. Research

- Better information on total numbers, spawning areas and the genetic structure is needed to evaluate the severity, probability and uncertainty about the interaction of domesticated escapees on wild populations.
- Studies are needed to determine the number and survival of escapees in the natural environment (in function of season and space, impact of escaped turbot in winter may be different from winter, due to the presence of natural predators, e.g. cod migrating to the north in winter). This is needed to evaluate the severity, probability and uncertainty about the interaction of domesticated escapees on wild populations.
- Development of tools to distinguish wild fish from wild population. For turbot, the morphology of reared turbot is slightly different in comparison with their wild counterparts. In turbot, as in other flatfish species, morphological differences are primarily seen as malpigmentation on the blind side to patches with lack of pigment and white pigment on the eyed side. Such malpigmented turbot are found in the wild but at much lower frequencies than in cultured turbot, as it is determined through the larval diet and possibly the rearing conditions. Further morphological characteristics, like the general form of the turbot, is highly influenced by the stocking densities in the culture tanks. Tagging could be a method, but due to high stocking densities in the tanks, these tanks could harm other turbots. The most common chemical compounds used to mark otoliths are alizarin compounds (Beckman and Schultz, 1996; Tsukamoto, 1985), calcein (Brooks et al. 1994; Wilson et al. 1987) and oxytetracycline (Dabrowski and Tsukamoto, 1986; Nagiec et al. 1988; Schmitt, 1984). Studies that address what levels of escapees will cause problems for local populations and their impact on the different life-cycle stages of their wild counterparts. Descrimination between reared and wild turbot is usefull to act after an accidental release of farmed turbot in the wild, in order to reduce the severity. Probability and uncertainty of escapees stays the same.

Final evaluation of unmanaged risk should be located on an Acceptable Level of Protection matrix with annotation to show the effect of uncertainty. Also plotted should be the level of risk associated with each of the risk management options.

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Annex 5: Update on developments in the implementation of the Water Framework Directive and EU Strategy for Sustainable Aquaculture

Introduction

WGEIM has, for the last two years, reviewed the implementation process of the WFD and attempted to address the potential implications of the WFD on mariculture in the absence of specific guidance from the authorities responsible for implementation. The purpose of this Term of Reference is to continue this, provide an update on the implementation process and clarification on some of the questions raised in previous reports.

The overall objective of the Water Framework Directive (2000/60/EC) is to bring about the effective co-ordination of water environment policy and regulation across Europe in order to:

- to protect and enhance the status of aquatic ecosystems (and terrestrial ecosystems and wetlands directly dependent on aquatic ecosystems);
- to promote sustainable water use based on long-term protection of available water resources;
- to provide for sufficient supply of good quality surface water and groundwater as needed for sustainable, balanced and equitable water use;
- to provide for enhanced protection and improvement of the aquatic environment by reducing / phasing out of discharges, emissions and losses of priority substances.

Implementation Deadlines

The implementation deadlines for the WFD are ambitious and extend to 2015 (see Table A5.1 for deadlines outlined in Irish legislation). The tasks and deadlines are outlined in a very presecriptive manner. Presumably this will result in consistent interpretation of the directive among member states as well as concurrent implementation of tasks. Failure to submit at the appointed time could lead to infraction proceedings against the member state.

Table A5.1. Implementation of the WFD as scheduled in Irish legislation (source: www.wdfireland.ie).

KEY DATES	KEY TASKS
22 December 2003	Implementation of the WFD on a National level
22 June 2004	Establishing of River Basin Districts as the fundamental unit for applying and co-ordinating the Directive’s provisions
22 December 2004	Characterisation of River Basin Districts.
22 June 2006	Develop Classification systems for surface water and groundwater
22 June 2006	Establishing and maintaining appropriate Monitoring Programmes - Such monitoring must cover both surface and groundwater and must be operational by 22nd December 2006.
22 June 2006	Prepare and publish a work Programme and Timetable for the production of River Basin Management Plans (RBMP).
22 June 2007	Prepare and publish an overview of the significant water management issues identified in each river basin.
22 June 2008	Prepare and publish draft RBMPs and allow six months for written comment.
22 June 2008	Publish a draft Programmes of Measures for comment by any person for a six month period.
22 June 2009	Establish environmental objectives and final Programmes of Measures and developing RBMPs for their implementation
22 June 2009	Publication of RBMPs
2010	Water Pricing Policies that take into account the principle of ‘cost recovery’ for water services
2012	Latest date for making operational the Programme of Measures
2015	Meet environmental objectives of first RBMP and adopt the Second RBMP

Cells shaded identify completed tasks.

Characterisation (Article V) Report

The publication of the Article V or Characterisation Report was the primary implementation goal for all member states during 2004. The Characterisation Report comprises:

- An analysis of River Basin District characteristics;
- A review of the impact of human activity on the status of surface waters and on groundwater; and
- An economic analysis of water use.

The principle objective of the report is to provide summary information on the initial waterbody characterisation at River Basin District (RBD) level. This initial assessment serves to identify those waterbodies that are either at risk or not at risk of achieving the Directives objectives by 2015. Following the initial Report in 2005, further characterisation of waterbodies designated as at risk or probably at risk will be undertaken leading up to the production of the draft River Basin Management Plans (RBMPs) in 2008. Final reporting to the EU Commission on Characterisation will take place in 2010 when RBMPs are finalised.

As identified above, based upon the objectives, the report was divided into a number of sections. First, groundwaters and surface waters (includes rivers, lakes, transitional and coastal waters and other wetlands) were physically characterised and divided into water bodies, the unit of reporting required by the EU, for management purposes. In addition, as surface waters are living aquatic ecosystems, the directive requires type-specific reference conditions to be established for all surface water types. This is the outcome of the typology exercise described in WGEIM 2004. The status of each surface water body will later be measured against these reference conditions.

Characterisation provides a better understanding of the current and predicted future state of all aquatic environments and the ecology associated with them. It helps to determine the future monitoring strategy and also provides a starting point for the design of the Programme of Measures (i.e., actions to improve the ecological status).

For all groundwaters and surface waters, significant environmental pressures were identified and impacts, where known, assessed. The risk posed to all water bodies in terms of whether or not they will achieve good status by 2015 was assessed based both on a predictive approach using readily available information and established relationships and on impact data derived from existing monitoring information where available. Based upon the pressures acting upon them, each waterbody was assigned to one of four risk categories:

- 1a – at risk of not achieving good status;
- 1b – probably at risk of not achieving good status;
- 2a – probably not at risk of not achieving good status;
- 2b – not at risk of not achieving good status.

Mariculture, as an activity in the marine environment, was assessed under the pressures and impacts analysis in some member states. Mariculture activities were considered as one of the pressures acting on the overall quality of water bodies and aquaculture sites were not separated out as distinct water bodies (see below). This is an important point of clarification relating to an issue raised in WGEIM 2004. Shellfish culture can have an impact on the seabed by reducing flow and causing a build up of sedimentary material in the vicinity of the structures and perhaps a buildup of organic material as a consequence of pseudo-fecal and fecal production. In areas of high density of shellfish production, there is a risk of phytoplankton depletion that may impact upon the culture organism and other suspension feeding organisms in the water body. Finfish aquaculture can also result in reduced flow conditions in the vicinity of the cage structures resulting in increased sedimentation and organic enrichment. There are also risks resulting from escapes, disease and parasites associated with finfish aquaculture activities. Monitoring programs may be in place in member states to assess the localized effects of aquaculture (and provide guidance on the potential risk categories), they do not usually specifically deal with risk to the status of the wider water body. In the case of shellfish, monitoring is typically confined to human health issues (bacteriological, harmful algal blooms and biotoxins) – there are no monitoring programs currently in place designed to assess the impact of extensive shellfish harvesting on the ecological status of a water body, as defined by the WFD.

As an example, in Ireland, bottom culture of mussels, because of its extensive nature was considered as a risk that might impact on the physical structure of the waterbody and was therefore considered to present a pressure under morphological assessment. In terms of other shellfish culture activities, given the distinct lack of information pertaining to the wider impacts on water bodies imposed by aquaculture activities and that aquaculture activities have inherent risks associated with them, all water bodies having licensed aquaculture activities were classed as 2a – probably not at risk but there is insufficient information to class as not at risk- 2b. It is important to point out that the assessment was not considered definitive and is subject to revision.

In Scotland, fish farming has been treated as a pressure acting on the receiving water bodies. It has been recognised that the intensity of fish farm activity varies between water bodies (sea lochs). The intensity of activity is the basis for Locational Guidelines for fish farming published by the Scottish Executive. This document classifies coastal waters into three categories, depending on the modelled inputs of nutrients and particulate organic matter. The most highly utilised lochs were assigned to Class 1b. Moderately used lochs were assigned to 2a, and relatively low intensity lochs were assigned to Class 2b.

In addition to the Characterisation Report, a register of areas already protected by EU legislation was also provided. Article 6 of the Directive requires Member States to establish a register of all protected areas lying within each river basin district. These are areas that have been designated under specific community legislation for the protection of their surface water or groundwater or for the conservation of habitats and species directly depending on water.

The influence of the WFD on mariculture operations

A number of questions were highlighted by WGEIM 2004 in relation to the possible impacts of WFD on mariculture operations within member states. These questions are repeated in the text below with the specific sections.

Water Body Classification

2004 Question: Will the lowest quality assessment direct the classification of the water body or will it be carried out by averaging out the quality at a number of locations within a water body?

The 2003 WGEIM noted, with reference to classification schemes, that "it was not yet clear how the national schemes, and subsequently the inter-compared schemes, will accommodate differences in the values of biological or hydro-chemical elements within water bodies. How this is to be done is clearly of importance to mariculture activities, as mariculture sites will present pressures on the environment and some of the elements of the assessment will be at less than reference status at these sites. Again, this question is not confined to mariculture. Many other anthropogenic activities that result in waste discharges are subject to the same uncertainties."

Some aspects of these issues have subsequently been clarified, for example it now seems clear that quality status assessments will be made against habitat-specific reference conditions for each of the relevant quality elements, and that the final overall status assessment will default to the lowest of the component assessments. Therefore, a water body assessed to be at high status for most quality elements, but at only moderate status for, say, benthic fauna, will be classified as of overall moderate biological status.

2004 Question: How will temporal and spatial averaging of ecological quality of water bodies be dealt with?

WGEIM 2004 noted that "significant uncertainties remained unresolved in other aspects of classification. Examples include:

Assessment of chemical data against EQS values. Chemical monitoring will be required on several occasions during the year, and the primary assessment tool will be the calculation of an annual average for comparison with the EQS. Additional complexities arise in the case of non-continuous inputs of chemcials, such as will occur in the case of periodic use of sea lice treatment chemicals at fish farms. Current guidance suggests that sampling programmes should be designed so that periods of high use (and potentially increased concentrations) are covered. However, how such temporally biased sampling should be used to calculate an annual average (e.g., by time-weighting each sample in some way) has not been defined. The details of the final procedure will be an important factor with regard to fish farm chemicals. Similar issues of temporal averaging will also be relevant to other quality elements where more than one sampling event will take place each year.

Spatial averaging of monitoring data. In addition to the temporal averaging questions discussed above, uncertainties remain in how data from more than one sampling location within a water body should be combined to derive an overall assessment of the water body for that particular quality element. Defaulting to the worst case may result in large water bodies receiving overall classifications dominated by results from single stations reflecting conditions in a small proportion of the whole water body, and might be viewed as giving a misleading impression of the water body as a whole. The influence of a small impacted area of sea bed below a fish farm on the overall classification of a larger water body is therefore not entirely clear.

In addition, many waste discharges, including those from aquaculture, result in degradation of environmental quality in the immediate area of the discharge outlet (e.g., a few metres round the end of a piped discharge, or on the sea bed immediately under fish cages). Current regulatory practices recognise that such areas of impact, areas where EQS values may be exceeded, are an almost inevitable consequence of waste disposal and many other activities in coastal waters. The extent of such zones are an important element of the assessment of the acceptability of these activities. Such assessments will currently include the risk of impacts on the wider ecosystem in the receiving waters, which in many cases will be managed through the application of appropriate EQSs. While the application of EQSs is very much in keeping with the WFD, for both (priority) hazardous substances and specific pollutants, it is not yet clear how the mixing zone concept will be accommodated within WFD."

In 2005, these uncertainties are largely still unresolved. There are indications to suggest that an averaging process will be applied to the metrics used within each of the biological quality elements (benthos, macroalgae, etc). Although not yet explicit, it seems likely that this process will be applied to spatial and temporal variation within water bodies to obtain an expression of the overall quality of the water body, incorporating both spatial and temporal variability. The implication of this process is that occasional samples that fail to meet particular thresholds/standards will not of themselves govern the final overall assessment of that particular biological quality element. This averaging process will lead to expression of status for each of the quality elements, and the final overall status will default to the lowest of these.

It is still too early to suggest how countries might be planning to define sampling programmes and locations within water bodies. However, countries are in the process of defining surveillance monitoring programmes (and soon operational monitoring programmes). Such definitions will require the development of policies and procedures on the approach to be taken to areas within water bodies where objectives may differ from those applicable to the bulk of the water body, or where additional objectives may apply. Examples of the latter include areas where special additional protection may be required, for example SACs under the Habitats Directive where particular care may need to be taken to protect the species leading to the designation, and monitoring should reflect these enhanced standards. Similarly, within mixing zones (water column) and zones of allowable effect (on the sea bed), it is likely that some quality objectives will not be met (this being the purpose of such zones), and monitoring should take account of this.

The conservation status of Natura 2000 sites has considerable relevance when considering the implementation of the Water Framework Directive (WFD) 2000/60/EC. Under the WFD good ecological status will be measured by;

- ecological quality elements;
- physico-chemical parameters;
- chemical status and in the case of European sites;
- conservation status.

All elements measured must attain the required standard. As outlined above, if even one element fails, the water body will fail overall. In other words, if the water body fails to meet acceptable conservation status, then the water body fails its objectives under the WFD. As a consequence of this relationship between the directives, the metrics used to assess ecological quality status and that of conservation status must be compatible. In addition, any metric that might be used to regulate aquaculture activities might also be compatible with the aforementioned metrics.

2004 Question: How will large-scale aquaculture activities (e.g., bottom culture of mussels), which may constitute large proportion of the seabed in a water body, be dealt with in the context of the directive?

2004 Question: What reference conditions will be utilised to classify these large-scale aquaculture areas, especially if the activity was originally carried out on habitat different from that created by the activity?

It was noted in the WGEIM 2004 that most countries had defined their water bodies. These tend to be large, on the scale of kilometres to low tens of kilometres, and therefore it has been resolved that the majority of mariculture activities will be considered as one of the pressures acting on the overall quality of the water body.

However, WGEIM 2004 noted that uncertainty remained as to the possible implications of WFD for other related activities, e.g., bottom culture of mussels and intertidal culture of oysters. These activities may impact on the benthos over wide spatial scales (on the order of km^2 and may be representative of that water body) and consequently may put the water body at risk of failing to meet good ecological status. Initial risk assessment efforts carried out by England and Wales has determined that the shellfisheries (even if comprising up to 50% of a water body) may not be considered of having high pressure on a water body. However, this exercise considered managed wild-fisheries only and not true aquaculture operations. In Ireland, a somewhat similar approach was taken whereby, the proportion of a water body subject to extensive aquaculture activities (i.e., bottom-culture of mussels) was considered and a level of risk was assigned based on selected threshold values (Table A5.2). This resulted in some areas classed as 1b (probably at risk of not achieving good status)

Table A5.2. Extensive aquaculture area thresholds assigned to a specific level of risk under the pressures and impacts analysis from Ireland.

WATER BODY PROPORTION	RISK CATEGORY
<15%	2b
15–45%	2a
45–90%	1b
>90%	1a

It is well recognised that the character of the seabed and benthic fauna in the area of a dense mussel bed is very different from that in areas without mussel beds. In addition, commercial fishing such as trawling or scallop dredging has been classified as a pressure on the morphology of the sea bed that can be (depending upon its intensity) a significant pressure on the quality on the benthic environment and associated fauna. It is therefore possible that monitoring may show that overall ecological status in some areas used for bottom cultivation of shellfish has been reduced. However, such assessments will be heavily dependent on the selection of reference conditions. Should the reference conditions reflect/accept the presence of the mussel beds, or should the mussel beds be considered as a pressure on the "normal" fauna of the area? The selection of appropriate reference conditions might be informed by the fate of these areas were the pressure removed (under programmes and measures). For example, if seeding and dredging operations ceased on bottom mussel culture beds (i.e., the most dramatic action that might occur to reduce the pressure), it is likely that in the majority of situations, the mussel communities would persist on the seabed in the short to medium term. It is unlikely that the areas would revert to sedimentary infaunal communities. Consequently, in this scenario the reference habitats governing these areas would be mussel communities and not sedimentary type habitats.

Finally, it must be remembered that many of these extensive culture areas are licensed for the aquaculture activities carried therein; however, the activities and impacts may be considered broadly similar to those realised by conventional fishing activities. Consequently, the question is raised whether this activity is considered as aquaculture or a fishing activity. It is unclear how this issue might be dealt with within the framework of the directive and what the consequences might be however, WGEIM will endeavour to answer this in subsequent reports.

Chemicals Used in Mariculture
2004 Question: From a temporal perspective, will measurements taken during periods of disturbance (e.g., elevated chemical use to treat sea-lice) not introduce a certain amount of sampling bias?

Assessment of chemical data against EQS values. Chemical monitoring will be required on several occasions during the year, and the primary assessment tool will be the calculation of an annual average for comparison with the EQS. Additional complexities arise in the case of non-continuous inputs of chemcials, such as will occur in the case of periodic use of sea lice treatment chemicals at fish farms. Current guidance suggests that sampling programmes should be designed so that periods of high use (and potentially increased concentrations) are covered. However, how such temporally biased sampling should be used to calculate an annual average (e.g., by time-weighting each sample in some way) has not been defined. The details of the final procedure will be an important factor with regard to fish farm chemicals. Similar issues of temporal averaging will also be relevant to other quality elements where more than one sampling event will take place each year.

In discussing the chemicals used in mariculture WGEIM 2004 noted that it was very likely that the chemicals used in fish farming activities will be considered as specific pollutants under Annex 8 of the Directive. This means that countries will be required to undertake chemical monitoring in water bodies where the risk assessment suggests that the quality may fail to attain overall good status, as a result of the discharge of these chemicals. The results from such chemical monitoring should be assessed against EQS values, which have been designed to protect the environment from unacceptable impacts from the chemicals concerned. Therefore, it is likely that EQSs will need to be developed for aquaculture chemicals, probably on a national basis.

One of the key factors in developing the chemical aspects of WFD is the preparation of the Article 16 Priority Substances Daughter Directive. This has been delayed, and a further draft is now not expected until summer 2005. In addition, there is considerable uncertainty as to the influence that chemical quality assessment may have on overall ecological status assessment. In one interpretation, the failure to meet background concentrations (i.e., undetectable by the most sensitive analytical methods in general use) would preclude a water body from achieving High overall status. It is conceivable that the detection of some fish medicines in the water column of water body which is otherwise free from significant pressures could therefore effectively downgrade that water body from potentially High Status to Good Status. While this should not of itself lead directly to mitigation measures, it could leave aquaculture in an exposed position, as the perceived cause of the downgrading.

Measures to Improve Ecological Quality (Mitigation Measures)

2004 Question: What programmes might be introduced to improve ecological quality with a water body as a consequence of an aquaculture activity?

The overall aim of the Water Framework Directive is the achievement of good water status in all waters by 2015. It is probable that the initial classification will result in some water bodies being classified as a having an ecological status below the target level. In such cases, Member States will then be required to take steps to improve the status of these water bodies. WGEIM 2003 and 2004 commented that suggestions that possible additional management and mitigative actions may be required of aquaculture operations in some areas where good ecological status has not been achieved remained to be confirmed.

WGEIM 2005 is not aware that any significant progress has been made in this area with respect to mariculture, and note that the Directive does not require the identification of a programme of measures for achieving the environmental objectives of the Water Framework Directive until 2009.

This is as yet unresolved; and it might be too early to even attempt to answer this question given that monitoring programs have not been implemented and programmes and measures do not come into effect until 2009. In the event of failure of a water body to meet at least good ecological quality status and this is attributed to an aquaculture activity – the activity must be modified in some fashion in order to mitigate the impact. Such mitigation may take the form of:

- Abolishing the culture activity altogether;
- Reducing the intensity of the culture organisms (e.g., fewer cages, interspersing fish cages with shellfish ropes, thinning beds);
- Adjusting timing of activities associated with the culture practice (e.g., carry out dredging activities at a specific stage of the tide or year);
- Adjusting the activities associated with the culture practice (e.g., multiple to single access routes in the intertidal area or perhaps modifying gear to harvest culture organism);
- Using different medicines.

EU Policy on Sustainable Aquaculture

WGEIM 2004 highlighted that there were currently no comprehensive rules at EU level regarding introductions, transfers and containment of aquatic organisms in aquaculture this reflects the view of Strategy document produced by the European Commission. In its Strategy document the Commission announced its intention to propose management rules for introductions, transfers and containment in aquaculture. Following consultation meetings during 2003 and 2004, draft regulations were circulated in March 2005. These regulations deal solely with the use of alien species in aquaculture. The development rules governing containment will be dealt with at a later date. The decoupling of the two subject areas was a consequence of feedback provided to the commission from a number of consultees.

The commission justified the production of these regulations because it was felt that there was a gap in current legislation (e.g., Habitats Directive 92/43/EC) such that the introductions may be effected in a non-deliberate manner or by virtue of alien species being used in non-wild environment. In addition, the regulations propose to address the issue of protection of a species native in one part of the community but is a potential nuisance in another.

The legislation is proposed in the current format to achieve the correct balance with regard to subsidiarity and proportionality. Decision making is left to Member States, which will be able to assess under prescribed conditions, the risks associated with proposals for introductions. Proponents of the use of alien species are obliged to produce a notification giving Member State authorities sufficient elements for judgment. The content of the notification, which is obligatory in all cases except for movements within the European territory of Member States, is sufficiently comprehensive to allow an evaluation of whether the movement would be routine or non-routine. It also provides sufficient criteria for a decision to be made at Member State level on whether an environmental risk assessment (ERA) is required. Evaluation of the completed ERA will in turn inform the decision making process on whether a permit should or should not be granted. A “Community procedure” allows the Commission to consult the other Member States and to consult the scientific committee in case an objection is raised. In this case the Commission can decide to confirm, cancel or amend the decision having obtained the opinion of the advisory committee. The time frame for decision making at Member State level is not determined whereas a strict eight month deadline is set for the Community procedure. The proposal draws heavily on the existing voluntary ICES/EIFAC Codes and on the Canadian National Code on Introductions and transfers of aquatic organisms which develops the ICES code significantly. It does not rule out the voluntary application of the ICES/EIFAC codes.

European Marine Strategy

The Commission services are currently finalising a proposal for a Thematic Strategy on the Protection and Conservation of the Marine Environment, due for adoption later in 2005. The following text is a summary of a published EU Consultation document.

The Marine Strategy is aimed at protecting Europe’s seas and oceans and ensuring that human activities in these seas and oceans are carried out in a sustainable manner so that we and future generations can enjoy and benefit from biologically diverse and dynamic oceans and seas that are safe, clean, healthy and productive.

The marine environment is currently subject to a variety of threats, ranging from the loss or degradation of biodiversity and changes in its structure, loss of habitats, contamination by dangerous substances and nutrients and possible future effects of climate change. If not addressed, these threats and pressures will put at risk the generation of wealth and employment opportunities derived from our oceans and seas.

While there are measures to control and reduce pressures and threats on the marine environment, there is no overall, EU level, integrated policy for protection of the marine environment. Therefore, an integrated approach taking into account all the pressures on the marine environment needs to be developed, setting clear sustainable objectives and targets to be met through a set of cost-effective measures.

There will be two main elements to the Marine Strategy; a Communication and a Framework Directive

The **Communication** would briefly describe the state of the marine environment, the pressures acting on the marine environment and the need for action. It will:

- set out an overall vision for the protection of the marine environment;
- describe why any approach to marine protection needs to recognise the differences in the character of the different marine areas in the EU;
- suggest an ecosystem-based approach, in line with the concept of sustainable development, which puts emphasis on a management regime that maintains the health of the ecosystem alongside appropriate human use of the marine environment, for the benefit of current and future generations;
- recommend the identification of ecosystem based marine regions as being the most appropriate level to prepare implementation plans;
- explain how the EU marine strategy will interface with non-EU countries and with the international and regional conventions and commissions which already exist for the protection of European regional seas.

The Communication would include the following overarching objectives and actions:

- To protect and, where practicable, restore the function and structure of marine ecosystems in order to achieve and maintain good environmental status of these ecosystems;
- To phase out pollution in the marine environment so as to ensure that there are no significant impacts or risk to human and/or on ecosystem health and/or on uses of the sea;
- To control the use of marine services and goods and other activities in marine areas that have or may have a negative impact on status of the marine environment to levels that are sustainable and that do not compromise uses and activities of future generations nor the capacity of marine ecosystems to respond to changes;
- To apply the principles of good governance both within Europe and globally.

The objective of the new **Marine Framework Directive** would be to protect, conserve and improve the quality of the marine environment in these marine waters, through the achievement of good environmental status in European seas within a defined time period. The Directive will define/establish ecosystem-based marine regions as the implementation unit. They will be defined on the basis of their hydrological, oceanographic and bio-geographic features.

An Implementation Plan, defined as an integrated framework for the adaptive management of human activities impacting on the marine region, would be prepared for each marine region. In preparing the plans, there would be an obligation,

- to assess the pressures and threats impacting upon the marine environment and the costs (including environmental costs) of these pressures.
- to develop a monitoring and assessment programme to be carried out in each sea according to general indications given in the directive but taking full account of the monitoring and assessment programmes which are already in place.
- On the basis of the assessment programmes and the monitoring information a draft Implementation Plan for each Ecosystem-based Marine Region would be drawn up. This Plan would include an identification of the measures needed to achieve the environmental objectives within the time frame required by the directive and an assessment of their environmental, social and economic costs and benefits.
- Finally, the directive would include provisions on monitoring and reporting.

WGEIM noted that the proposed Marine Directive contained a number of elements that were similar to those in the Water Framework Directive. These included objectives, method of implementation, and monitoring/reporting requirements. It would therefore seem logical that the Marine Directive would be applied to those marine areas seaward of the boundary of the area currently being covered by the WFD (more than 1 or 2 miles offshore).

However, there is currently some lack of clarity in this area, and it may be that the Marine Directive would apply to coastal and transitional waters as well as to offshore waters, i.e., overlap with the WFD in these areas. If this is the case, then the Marine Directive would apply directly to European areas that are currently utilized for mariculture. In view of the likely similarities between the Marine Directive and the WFD, it is likely that the uncertainties noted in the implications of the WFD for aquaculture would also apply to the Marine Directive.

If the Marine Directive only applies to offshore waters, there will be much less immediate interaction with aquaculture. Little, if any, European or North American aquaculture takes place more than 1–2 miles offshore (apart from a few areas, for example the Gulf of Mexico). However, the gradual reduction in the availability of near-shore sites for aquaculture may lead to attempts to establish offshore production units (for example in association with offshore wind farms), and in that case it is likely that the Marine Directive would be a relevant consideration. It is therefore important that Members of ICES should bear the needs of aquaculture in mind during future negotiations on the Marine Directive.

Annex 6: Review of recent development in carrying capacity models for shellfish and recommendations for future directions.

Introduction

One of the most contentious issues with respect to the development of mariculture throughout the world is the concept of "carrying capacity". Debate on this concept is often fuelled by the lack of a clear and concise definition of the term which can be interpreted on a wide scale of values that include physical, biological, economic, and social parameters. Thus, for the purpose of this discussion on carrying capacity for shellfish mariculture, we will adopt the definitions of Inglis *et al.* (2000) who partition carrying capacity into four functional categories:

a) *Physical Carrying Capacity* - the total area of marine farms that can be accommodated in the available physical space;
b) *Production Carrying Capacity* - the stocking density of bivalves at which harvests are maximized;
c) *Ecological Carrying Capacity* - the stocking or farm density which causes unacceptable ecological impacts;
d) *Social Carrying Capacity* - the level of farm development that causes unacceptable social impacts.

The objectives of this paper are to 1) give an overview of these four different categories of carrying capacity without redoing the work that has been done elsewhere, 2) give a more in-depth review and list the factors that could be considered for category iii as this category is the least developed in terms of predictive power, 3) outline a decision framework for incorporating all four categories into the determination of the overall carrying capacity of a given area for bivalve culture, and 4) outline future research areas that might address knowledge gaps for *ecological carrying capacity* studies.

1. Overview of "Carrying Capacity" categories

Physical Carrying Capacity

The concept of *physical carrying capacity* describes the area which is geographically available and physically adequate for a certain type of aquaculture. It depends on the overlap between the physical requirements of the target species and the physical properties of the area of interest (e.g., type of substrate, depth, hydrodynamics, and temperature). Physical properties should also include some basic chemical parameters (e.g., salinity and dissolved oxygen concentration) but not biological or organo-chemical parameters (e.g., particulate organic carbon or chlorophyll concentration), which are addressed when calculating *production* and *ecological carrying capacity*. The *physical carrying capacity* of an area also depends on the culture technique, e.g., areas which are adequate for suspension culture may not be for bottom culture and *vice versa* (due to bathymetric or hydrodynamic constraints).

The concept of *physical carrying capacity* is straight-forward without feedback from the aquaculture activity. It may be best addressed using hydrographical models to assess areas of interest based on their physical properties and the physical (culture type) and biological requirements of the species of interest. The pertinent data is then analysed using Geographic Information Systems (GIS) (Congleton *et al.*, 1999; Arnold *et al.*, 2000; Nath *et al.*, 2000; Pérez *et al.*, 2002).

Production Carrying Capacity

The *production carrying capacity* is the achievement of optimum production of the target species and is achieved by modifying the stocking density and yield of the target species, in this case filter feeding shellfish. For filter feeding shellfish, it will mainly depend on natural resources and will therefore become interactive the ecosystem (e.g., Carver and Mallet, 1990; Bacher *et al.* 1998). *Production carrying capacity* may be measured, *inter alia*, in terms of wet or dry weight, energy or organic carbon. It greatly depends on the *physical carrying capacity* and the functions of the ecosystem, especially primary production within the area of interest and, often of even more importance, the importation of organic matter. Furthermore, positive and negative feedback mechanisms between the culture activities and the ecosystem need to be considered.

Several reviews have already been carried out on this subject, including a series of papers published in a special issues of Aquatic Ecology (volume 31(4), 1998) and the Journal of Experimental Marine Biology and Ecology (volume 219(1–2), 1998), a scoping study in Great Britain (Davies and McLeod 2003) and an overview in New Zealand (Inglis *et al.*, 2000). The output of these reviews demonstrate that there are a wide range of modelling approaches focusing mainly on food availability and production, bivalve feeding and physiology and the influence of husbandry practices on crop production, as well as the interactions among these factors. The recent review by Kaiser and Beadmen (2002) on production carrying capacity along with the more recent developments in this field as discussed in this text suggest that, for most commercial shellfish species, the ability to assess and predict the effect of stocking densities of bivalves on their production is well developed and has been applied in a wide range of ecosystems. The main constraint of these models is in their limited ability to determine feedback mechanisms, i.e., the effect of the ecosystem response on their activity. A further shortcoming on this category of modelling is that it is usually limited to the ongrowing phase and does not address the seed collection, harvesting, and processing phases. Finally, production carrying capacity may also depend on the culture technique (e.g., bottom versus suspended culture) and the geographical distribution of the culture sites in the area of interest. Although these are critical aspects, that should be investigated and developed, they will be addressed more efficiently in the following section on ecological carrying capacity.

Ecological Carrying Capacity

While modelling of *production carrying capacity* focuses on the target shellfish species and on factors that are directly linked to their production, modelling of *ecological carrying capacity* must theoretically consider the whole ecosystem. Practically, the society or their representatives must restrict this task by defining components of interests (e.g., species or habitats) and acceptable levels of change for each of these (i.e., *social carrying capacity*). *Ecological carrying capacity* will typically be quantified in terms of production of shellfish but needs to include limiting factors such as seed availability and the total usable area.

In contrast with *production carrying capacity*, there have been fewer efforts and successes in developing models to assess and predict the *ecological carrying capacity* of areas for bivalve culture. Also, as for *production carrying capacity*, the few attempts to develop modelling capacity in this field have been limited to the ongrowing phase of cultivation without considering all aspects of the operations and more importantly the interactions with other activities from an integration perspective.

Social Carrying Capacity

The *social carrying capacity* is to some extent even more complex than the *ecological carrying capacity*. It relies on the output from the previous three categories of carrying capacity analysis and aims at developing a comprehensive integrated management strategy based on tradeoffs between all stakeholders to maximize benefits in order to meet the demands of both the population (socioeconomic factors such as traditional fisheries, employment and recreational use) and the environment (Dolmer and Frandsen, 2002; Hoagland *et al.*, 2003; Stead *et al.*, 2003). The WGEIM (1998, 1999) has already reviewed the decision support system SIMCOAST and at present has nothing new to add to the recommendations given at that time.

Development of this category is at the heart of Integrated Coastal Zone Management (ICZM) and it must be fully developed so that responsible management decision may be made (Kaiser and Stead, 2003).

2. Review of Ecological Carrying Capacity

The concept of ecological carrying capacity is often driven by the public perception of negative environmental effects of aquaculture (Stickney, 2003), which is mostly based on finfish operations. This is partly because aquaculture, especially the culture of carnivorous fish species in netpens, commonly produces strong organic gradients leading away from culture sites (Cromey *et al.*, 2000). This is a result of aquaculture operations, especially those in open water net farms, being leaky systems with a proportion of the material added to grow the animals of interest ending up in the surrounding environment (Schendel *et al.*, 2004). This addition of organic matter basically swamps the assimilative capacity of the local environment, thus sometimes changing the physical, chemical, and biological structure of the bottom. However, strong gradients are not limited to fish cage farms and increasing evidence shows that the culture (grow-out) of bivalves may also have considerable influences on the benthic environment (Kaiser *et al.*, 1998). In short, bivalves growing in suspension feed on detritus, phyto- and zooplankton in the water column, using part of what is filtered for growth and consolidating the remaining fraction as either faeces or pseudofaeces, which sinks relatively quickly to the bottom, potentially increasing the accumulation of organic material in the vicinity of the site. For both types of aquaculture, the "footprint" or areal size of the impact is a function of many factors, including the size and age of the farm, the species being cultivated, and local hydrodynamic and natural benthic conditions (Black, 2001).

To date, research on the environmental effects of aquaculture has largely focussed on benthic processes as they relate to increased deposition of organic matter (Carroll *et al.* 2003). Despite the evidence that aquaculture sites may influence local benthic infaunal (i.e., invertebrates in the bottom sediments) communities (i.e, altering their structure), little work has addressed issues about their productivity and sustainability. Similarly, little research has been directed at examining interactions between bivalve aquaculture and the abundance and productivity of large benthic invertebrates, such as crabs and lobster, and fishes (Munday *et al.*, 1994). Further, much work to date has concentrated on near-field effects, ignoring far-field effects. Such effects are rarely discussed (but see Davenport *et al.*, 2003). What's more, when they are, often mostly negative effects are considered, largely ignoring potentially positive ones (see, for example, Gibbs, 2004). A more holistic approach is needed to determine the influence of bivalve aquaculture on the environment and the *ecological carrying capacity* of the environment for bivalve culture.

There is much scientific literature showing that the abundance of fish and macroinvertebrates is greater in areas on or immediately surrounding artificial reefs (ARs - structures placed on the bottom of the sea by humans) (Jensen 2002) and fish aggregation/attraction devices (FADs – structures positioned in the water column or at the surface of the water) (Castro *et al.* 2002), relative to areas distant to them. Aquaculture sites may function in a manner analogous to these structures (Costa-Pierce and Bridger 2002; Olin 2002; Davenport *et al.* 2003). The remainder of this chapter will address interactions with respect to bivalve culture.

There are many examples of how bivalve culture may have a net positive effect on ecosystem functioning. For example, Tenore *et al.* (1982) suggested that intensive mussel aquaculture in the Ria de Arosa, Spain, increases the production of fishes there, although there was no direct evidence given. However, other work done in the same area found increased abundances of several fish species in areas with mussel aquaculture (Chesney and Iglesias) and that the diet of numerous fish (Lopez-Jamar *et al.*, 1984; Fernandez *et al.*, 1995) and crab (Freire *et al.*, 1990; Freire and Gonzalez-Gurriaran, 1995) species consisted largely of epifauna from mussel lines. This is also consistent with the observation by Nelson (2003) that fishes are much more attracted to fouled FADs than clean ones. Preliminary observations in the Magdalen Islands, Quebec, have also found increased abundances of benthic fishes, crabs, and lobsters in mussel farms, as compared to control locations. The extent to which such increases in abundances of fishes and benthic macroinvertebrates translate into a heightened productivity remains largely unknown.

Several lines of evidence suggest that an increased abundance of several species at mussel aquaculture sites in the Magdalen Islands, Quebec, Canada, may indeed lead to an increased productivity of these species through a complex cascading effect of aquaculture on the local environment. Winter flounder (*Pseudopleuronectes americanus*) is one of the dominant fish species in the lagoons of the Magdalen Islands and seems to most abundant within mussel farms there. This species is particularly susceptible to predation by sand shrimp (*Crangon septemspinosa*), which are ubiquitous in most coastal areas in northeast Canada, including the Magdalen Islands, and this susceptibility is size-dependent (Taylor, 2003). Thus, the faster they grow and attain a size refuge from predation, the greater their contribution to overall productivity. Winter flounder shift their diet with ontogenetic stage, the smallest sizes depending mostly on small polychaetes (Stehlik and Meise, 2000), which often dominate under mussel aquaculture sites because of increased nutrient loads (Mattsson and Lindén, 1983). The latter is also the case in the Magdalen Islands (M. Callier, personal observations). Our observations that only the smallest size classes of winter flounder are more abundant under mussel lines support the model that mussel aquaculture increases the productivity of this species. Both lobster and rock crabs (*Cancer irroratus*) feed opportunistically on a variety of benthic invertebrates, including the mussels that fall from the longlines in the aquaculture sites, the former also feeding on the latter (Sainte-Marie and Chabot, 2002). Our observations in the Magdalen Islands and elsewhere suggest that there is often an abundance of mussels on the bottom from aquaculture sites. Taken together, this suggests that the growth and productivity of both lobster and crabs may also be increased in the vicinity mussel farms.

The production of epibiota (e.g., crabs, sea stars) on the mussel lines and other structures in mussel aquaculture should also be considered in the context of determining the total productivity associated with mussel aquaculture. The biomass and diversity of such epibiota may be substantial (Carbines 1993; Kilpatrick 2002; see LeBlanc *et al.* 2002 for a recent review) and may contribute considerably to the total productivity of the site. For example, recent work by Inglis and Gust (2003) suggests that mussel farms in New Zealand may also increase not only the abundance, but also the productivity of sea stars.

In sum, the interactions between aquaculture and the environment are far from simple. Historical understanding of these interactions is limited to near-field effects and only a limited number of these (e.g., impacts on sediments and communities). Ongoing research in Canada (http://www.aquanet.ca/English/research/an4.php) will help address questions relating to ecosystem-level interactions. But these are doubtlessly very complicated and results are forthcoming.

In some sense, models for calculating the *production carrying capacity* will also go some way to determining the *ecological carrying capacity* of an area for bivalve culture as this will tell us at what point some of the most important filter-feeders in the system (i.e., the bivalves in culture) are having a negative feedback on themselves (and presumably other filter-feeders in the environment). Such models vary greatly in complexity from simplified 2-D box models to more complex 3-D finite element models with hydrodynamics driving the model. Typical variables included are nutrients, phytoplankton, zooplankton, the farmed species, and detritus as well as varying levels of complexity of interactions among these components (feedbacks among these variables, temperature-dependent interactions, etc) (Dowd, 2005). More complex models are also being developed to include polyculture (e.g., Duarte *et al.*, 2003; Nunes *et al.*, 2003), suggesting that this approach to develop more complex "ecosystem" models may also be useful for determining the *ecological carrying capacity* of areas. However, such an approach would require a better understanding of the biology of the other species to be included in the models (although useful estimates may be obtainable for related taxa). A promising method of combining biological observations with nonlinear, non-Gaussian ecosystem models using a probabilistic, or Bayesian, approach has been recently suggested to predict bivalve-environment (mussel-plankton-detritus) interactions and *production carrying capacity* for coastal areas (Dowd and Meyer, 2003).

At this time, two main classes of research are being advanced to determine the *ecological carrying capacity* of ecosystems for bivalve culture. The first of these uses the output from a spatially explicit hydrodynamic-dependent particle tracking models to predict (organic) flux from culture sites to the bottom. A quantitative relationship between flux and a benthic community descriptor is developed and then used to predict the influence different levels of bivalve culture on benthic community structure (Henderson *et al.*, 2001). Although initially developed for finfish aquaculture, the DEPOMOD program (Cromey *et al.*, 2002) has also been used to this end for mussel aquaculture in Ireland (Chamberlain 2002), and is also being evaluated in Canada (http://www.dfo-mpo.gc.ca/science/aquaculture/acrdp-pcrda/quebec/Q-03–01–001_e.htm). In Canada, the modelling (and validation) study is being complemented by manipulative studies to show the dose (flux) – response (community type) relationship. Management decisions regarding stocking densities will then be able to be made based on predicted (benthic) environmental outcomes.

There are a number of limitations with this approach, not all of which are unique in a bivalve culture context.

First, there are limits with respect to the hydrographic part of the model. DEPOMOD assumes a homogenous flow field, i.e., that currents do not vary spatially throughout the grid. (This stems from the fact that the model was developed to be used as a simple tool to evaluate finfish culture in Scottish fjords for which accurate 3-D hydrodynamic models are typically not available or realistically possible to develop without undo expense and effort.) Although this may be a reasonable assumption for comparatively small areas as encountered for point sources in finfish culture modelling, this is likely not the case for more extensive shellfish culture that may cover several square kilometres. Although the model may handle complex systems (e.g., with islands, changing bathymetry, heterogeneous bottoms, slopes, multiple sites, etc.), it appears to have difficulties with such systems. As for most modelling, the user must have a good understanding of the study area before beginning the modelling work.

Second, the resuspension component of the model has not been fully developed for bivalve aquaculture, is assumed to be static throughout the study site and cannot be modified by the user. The resuspension of sedimented material is complex (depends on sediment type, cohesiveness, flocculation, degradation, etc.) and clearly varies both spatially and temporally. Presently, the resuspension module has been validated for Scottish fjords (salmon farms). More studies are required to validate the current default values used in DEPOMOD (i.e., critical erosion threshold, consolidation time, etc.), especially for bivalve culture. Recent work by Tony Walker (Dalhousie University, Canada) and several colleagues is addressing this point.

Third, the choice of the benthic community descriptor used in the model. By default, the model uses the infaunal trophic index (ITI) (Word 1979a, 1979b) and there is some controversy over the validity of this index. Other more recently-developed indices (e.g., Weisberg *et al.*, 1997; Borja *et al.*, 2000; Llansó *et al.*, 2002a; Llansó *et al.*, 2002b; Simboura and Zenetos, 2002; Salas *et al.*, 2004; see also Annex 6) may be more appropriate and could easily be used in lieu of the ITI, although these too remain to be fully validated.

Fourth, the model has yet to be fully validated in many areas under different environmental regimes (see above) so that its applicability may be considered to be general. Further, although this approach may be useful for a suspended culture system, its utility for bottom culture is doubtful and it does not consider other aspects of bivalve aquaculture that may exist, such as dredging for spat and harvesting.

Finally, this approach considers only the benthic component and thus its utility in determining the *ecological carrying capacity* for the entire ecosystem within an area is not possible.

The second approach that is being followed to determine *ecological productivity capacity* is the use of mass-balance / food web models. Early conceptual mass-balance models involved examining the influence of bivalve culture as a part of the ecosystem (Tenore *et al.*,1982) but not as a model to predict *ecological productivity capacity*. More recent work has used ECOPATH (Christensen and Pauly, 1992) in order to determine the trophic functioning of areas that include bivalve culture in Chile (Wolff 1994), Taiwan (Lin *et al.*, 1999), South Africa (Stenton-Dozey and Shannon, 2000), Brazil (Wolff *et al.*, 2000), and Italy (Brando *et al.*, 2004). These models differ considerably in their complexity (i.e., number of trophic groups considered) and completeness. Predictably, the presence of bivalve culture is typically seen to promote short energy pathways with high trophic efficiency and may contribute considerably to energy cycling in the studied systems. The aim of these works, however, was not to specifically determine the *ecological carrying capacities* of the areas under consideration, although this was at times evaluated (e.g., Wolff, 1994). A recent paper (Jiang and Gibbs, 2005) specifically attempts to determine the carrying capacity of an area in New Zealand for bivalve culture using a mass-balance approach and the ECOPATH model. Interestingly, they found that although the *production carrying capacity* of the area was 310 t yr^{-1}, the *ecological carrying capacity* of the area was only was 65 t yr^{-1}, above which point there would be major changes in energy fluxes within the system's food web. Future work is planned by Jeanie Stenton-Dozey (pers. comm.) to compile an ECOTROPHIC model of the Hauraki Gulf, New Zealand, to develop a sustainable fisheries and aquaculture industry in the region.

As with DEPOMOD, this approach also has limitations. First, the models used are typically steady-state and thus temporal variation in processes may not be included. Second, the mass balance model typically used (ECOPATH) is not spatially explicit. Thus the model may not be used to differentiate between near-field and far-field effects. Third, an understanding of many biological parameters (life history values, interactions, etc) is sorely lacking. And finally, this method, again, typically only considers the ongrowing phase of the culture, mainly based on plankton depletion and deposition of organic material; other phases need also to be studied and understood. An abridged list of the activities associated with various stages of bivalve culture that should be considered when determining carrying capacity (all types) is given below:

1) **Seed collection:**
   a. Dredging:
      i. disturbance of benthic communities, especially the removal of long-living species;
      ii. increase recruitment success and removal of juveniles from wild populations of target species;
      iii. collection of non-target species;
      iv. suspension of sediments;
      v. release of H_2S and reduction of dissolved oxygen in the water due to oxygen-consuming substances, release of nutrients.

b. artificial collectors:
    i. removal of juveniles from wild population of target species;
    ii. increasing target and no-target species recruitment success;
    iii. alteration of the hydrodynamic regime;
    iv. acting as FAD;
    v. risk of entanglement for large vertebrates (e.g., marine mammals, sea birds, turtles, sharks).
c. hatcheries
    i. chemical pollution (e.g., pharmaceuticals);
    ii. genetic selection;
    iii. spread of diseases.
d. Importation:
    i. introduction of alien species;
    ii. genetic pollution;
    iii. spread of disease.s

2) **Ongrowing:**
e. effects common to all techniques:
    i. organic enrichment of seafloor;
    ii. providing reef-like structures;
    iii. alteration of hydrodynamic regime (current speed, turbulence);
    iv. food web effects: competition with other filter feeders, increasing recycling speed of nutrients, removal of eggs and larvae of fish and benthic organisms;
    v. spawning: larval release from farmed and associated species;
    vi. providing food for predators of shellfish;
    vii. control of predators and pests.
f. Bottom:
    i. activities to prepare the culture plots, e.g., dredging for predator removal;
    ii. removal of associated organisms by dredging and relaying;
    iii. competition for space with wild benthos organisms;
    iv. creation of artificial reefs (physical and biological).
g. water column structures (trestles, poles, rafts, longlines, etc):
    i. acting as artificial reef or FAD (attraction/displacement or enhancement of animals);
    ii. behavioural disturbances and risk of entanglement of large vertebrates (e.g., marine mammals, sea birds, turtles, sharks).

3) **Harvesting:**
h. effects common to all techniques:
    i. alteration of biomass, nutrients;
    ii. removal of non-target species;
    iii. competition with predators;
    iv. scheduling (temporal).
i. Dredging:
    i. disturbance of benthos communities, especially removal of long-living species;
    ii. suspension of sediments;
    iii. release of H_2S and decrease of dissolved oxygen in the water due to oxygen-consuming substances, release of nutrients.
j. collection of off-bottom structures.

4) **Processing:**
k. dumping of by-catch;
l. relaying near auction houses;
m. depurating;
n. dumping of shells;
o. effluents from processing plant.

3. Decision framework to evaluate the carrying capacity of an area

We promote a hierarchical approach to determine the carrying capacity of an area for bivalve culture (Figure A6.1). At the first level, the *physical carrying capacity* of the site is determined based on the available natural conditions and the needs of the operation and bivalves to be cultured. Second, the *production carrying capacity* of the available area will be calculated based on modelling efforts. Third, the *ecological carrying capacity* of the area will be estimated, again with modelling efforts, by evaluating the range of possible outcomes for production estimates varying between none (and/or the current level) and the maximum calculated as the *production carrying capacity* (Figure A6.2). For example, an ecologists/scientists could use DEPOMOD to predict the spatial extent of dispersion of biodeposits from a proposed aquaculture operation at various stocking densities and configurations and predict how the benthic community would change along potential depositional gradients. Finally, managers would weigh and balance the different scenarios based on the outcomes from each of the preceding calculations of carrying capacity and competing interests and make a decision as to what level of productivity is acceptable – the *social carrying capacity*.

In contrast to *physical* and *production carrying capacity*, both *ecological* and *social carrying capacity* depend on social values. Thus, before being able to determine the *ecological carrying capacity*, the society must define environmental parameters of interest (e.g., bird and fish populations, clarity of the water, eelgrass or specific rare habitats). Ideally, the ecologists/scientists in charge should then be able to select suitable tools from a tool-box (e.g., models, GIS, and comparisons with previous studies) and predict for a range of production levels scenarios regarding these parameters. The society will then have to define the level of change it is willing to accept (i.e., the ecological carrying capacity). Finally, the interests of all stakeholders need to be addressed (e.g., shipping, recreation, tourism, sewage effluents, etc.), ideally within an ICZM plan, in order to assess the *social carrying capacity* of the management area.

It is important to note that output from the first three categories of models outlined above may or may not be available to the managers making socioeconomic-based decisions (i.e., determining the *social carrying capacity*) because of a paucity of scientific support and resources. Thus managers will likely have to rely on instinct, local knowledge, extrapolation from studies done elsewhere, etc. This does not however remove the logic of the hierarchical nature of the decision tree outlined above and the process should be followed using all available information in order to derive an unbiased view of the situation and thus make appropriate management decisions. Failure to follow this process (by, for example, stating out of hand that certain types of development or developments in certain areas are not permitted) will likely result in otherwise feasible bivalve culture installations not being initiated. This is clearly not in the interest of effective and transparent ICZM.

4. Knowledge gaps and research needs for *ecological carrying capacity* studies

The WGEIM suggests that work should be done on the following subjects as they relate to *ecological carrying capacity* studies:

- Studies must be done to better understand the role of various types of bivalve culture installations (and other steps in bivalve aquaculture) in the environment, with a balanced emphasis on both "negative" and "positive" influences;
- Existing models must be made spatially explicit;
- Temporal variation must be built into existing models;
- Models must be validated in a number of locations to evaluate their generality.

The WGEIM also recommends that a special theme session at the ICES Annual Science Conference on *ecological carrying capacity* for shellfish aquaculture be held with the following objectives:

- Update on recent advances in *ecological carrying capacity* research and use;
- Determine similarities with other food production sectors;
- Prepare a review paper with recommendations on future developments.

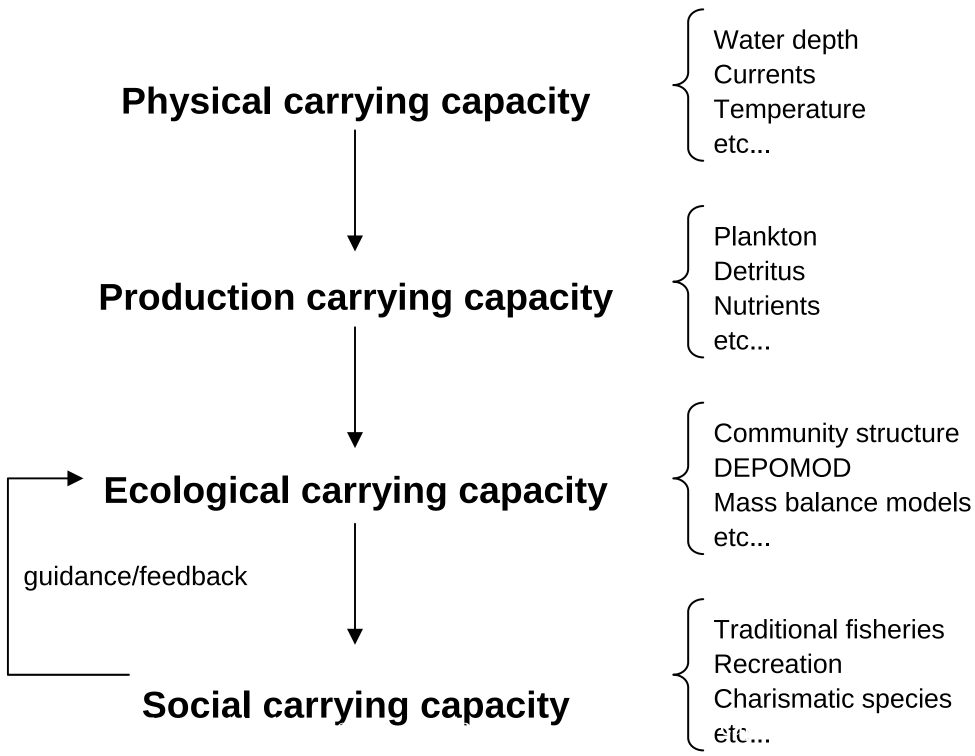

Figure A6.1. Hierarchical structure to determine carrying capacity of a given area. Note that *social carrying capacity* feeds back directly to *ecological carrying capacity* to provide guidance to choose pertinent response variables to measure.

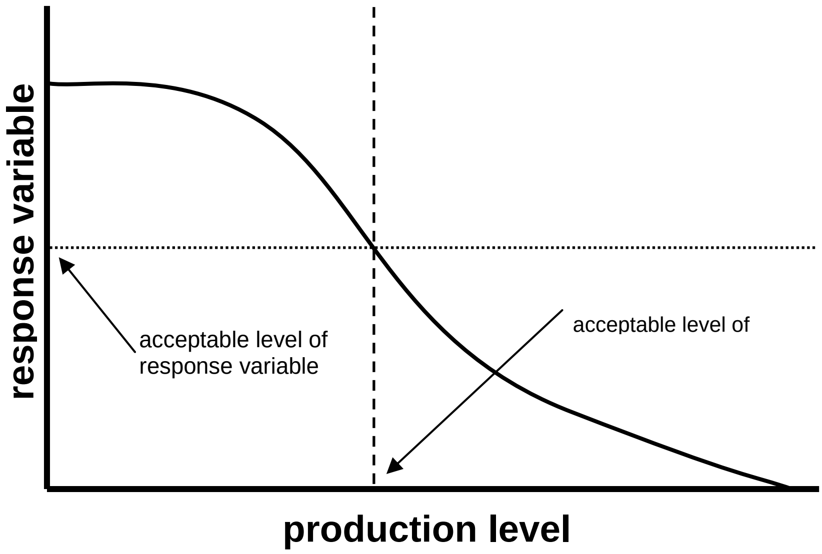

Figure A6.2. Hypothetical response curve of environmental variable under the influence of varying levels of bivalve culture production. The dotted line indicates the level of the indicator that has been determined to be acceptable by managers and the dashed line the corresponding level of production (i.e., the *social carrying capacity*).

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Annex 7: A preliminary evaluation of the possibility for developing a "sustainability index" concerning environmental interactions of mariculture

The many definitions of sustainability

There are many definitions of "sustainability", both general and those that define environmental sustainability (Table A7.1). The most popular definition of sustainable development is to "meet present needs without compromising the ability of future generations to meet their needs" adopted at a UN conference in 1987 (WECD, 1987). Robert Gillman, editor of *In Context* magazine, extends this goal-oriented definition by stating "sustainability refers to a very old and simple concept - The Golden Rule - do onto future generations as you would have them do onto you."

The many definitions of sustainability embody the concepts of "stewardship", "design with nature," the concepts of "polluter-pays", the "precautionary principle", and as well as "carrying capacity," the latter a highly developed modelling technique used by scientists and planners. As well, sustainability includes considerations of:

- more comprehensive planning for multiple impacts, with greater involvement of multiple disciplines in decision-making, and considering not only economic impacts but environmental and social as well;
- better planning for long term consequences of present development options; and
- incorporation of externalities in planning for site-specific developments.

Sustainability is a concept much broader than planning for site-specific impacts; it also accounts for systemic impacts off site. WECD (1987) stated that sustainability is using and not harming renewable resources and unique human-environmental systems of a site - air, water, land, energy, and human ecology - and/or those of other [off-site] sustainable systems.

The rationale for developing sustainability Indices (SIs)

Managers are flooded with large amounts of information for resource management – environmental, economic and social including governance and policy matters. SIs may offer cost-effective methodologies for managers to help simplify and prioritize the effective allocation of management resources.

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:

1) 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;
2) Socioeconomic: represent the demographics of humans in the coastal zone and measure quality of life issues;
3) Governance: measure the performance of the state of implementation, measuring the progress and quality of interventions of the governance process in relation to program goals set at the outset.

In relation to environmental policy-making, environmental indicators are used for three major purposes:

1) To supply information on environmental problems in order to enable policy-makers to value their seriousness;

2) To support policy development and priority setting by identifying key factors that cause pressure on the environment;
3) To monitor the effects of policy decisions (Smeets and Weterings, 1999).

Indicators must be measurable objects that can be simplified by aggregation and calculation. Outcomes from theoretical models cannot be considered as indicators. Nevertheless, models may help to indicate the most relevant factors to be monitored. Ideally, indicators must address the following issues:

- Continuity of supply (environmental, economic, and social services);
- Social, economic and environmental costs to provide this continuity of supply;
- Long-term aspects;
- Financial viability;
- Social and ecological impacts;
- Global efficiency.

Communication is the main function of indicators - they should enable or promote information exchange regarding the issue they address. Our body temperature is an example of an indicator we regularly use. It provides critical information on our physical condition. Likewise, environmental indicators provide information about phenomena that are regarded typical for and/or critical to environmental quality (Smeets and Weterings, 1999).

Environmental indicators may be used as a powerful tool to raise public awareness on environmental issues. Providing information on driving forces and impacts and connecting them to policy responses is an important strategy to strengthen public support for environmental policy measures. However, communication demands simplicity, and are important tools to focus attention on certain environmental aspects which are regarded relevant to society, and on which credible data are available. Indicators always simplify complex realities, and their significance goes beyond that obtained directly from the observed properties. Environmental indicators communicate those aspects regarded critical or typical for the complex interrelation between natural species and abiotic components of the environmental system.

There is a great deal of on-going activity on the development of indicators for coastal areas throughout the world (Table A7.2). European Union Member States are currently developing standards and indicators at both the national and regional scales as part of their collective work towards the Water Framework Directive (Annex 5). Ireland has completed a review of the application of marine environmental indicators to that nation's marine ecosystems (Boelens, *et al.*, 2004). The Department of Fisheries and Oceans Canada (DFO) is engaged in developing ocean indicators (environmental, socio-economic and governance) that will be used to follow trends and make decisions regarding a number of diverse coastal settings in support of the integrated management of Canadian oceans (DFO, 2004). DFO intends to make a long-term commitment to indicator development as part of its iterative cycles of planning for both reporting and performance evaluation (DFO, 2004).

The Development of SIs for Aquaculture

Sustainability concepts rely upon considerations of the fundamental components of societies throughout the world - the environment, the economy, and the society (the "3 P concept" of people, profit, planet). For aquaculture, Frankic and Hershner (2003) stated that aquaculture sustainability refers to the ability of a society to continue functioning in the future without being forced into decline through exhaustion or overloading of key resources on which aquaculture systems rely.

While a number of coastal environmental indicators are in current use, these require integration and outside expert evaluation as to their relevance to aquaculture. Indicators of the effects of aquaculture on the environment have been proposed:

- the Infaunal Trophic Index used by Scottish Environment Protection Agency;
- the AZTI Marine Biotic Index (Borja *et al.*, 2000; Borja *et al.*, 2003); and
- the Benthic Quality Index (BQI) for classification of marine benthic quality according to the European Union Water Framework Directive.

The BQI appears to be and significant step forward in environmental quality assessment across different benthic ecosystems (Rosenberg *et al.*, 2004). However, all of these indicators tend to be complicated, require considerable taxonomic expertise, are not easily implemented and are not in current use by aquaculture operations.

Costa-Pierce (2002) defined "ecological aquaculture" as an “alternative model of aquaculture research and development that brings the technical aspects of ecological principles and ecosystems thinking to aquaculture, and incorporates—at the outset—principles of natural and social ecology, planning for community development, and concerns for the wider social, economic, and environmental contexts of aquaculture”. The six characteristics of ecological aquaculture are:

1) preservation of the form and functions of natural ecosystems. Sites do not disrupt or displace valuable natural ecosystems; but if localized displacement/degradation does occur, active research and development programs for ecosystem rehabilitation and enhancement are initiated and sustained,

2) practices trophic level efficiency as the world’s most efficient protein producer, relying on plant, waste animal or seafood processing wastes, with fish meal used in the production process not as the major protein or energy source but to solve issues of diet palatability only,

3) practices nutrient management by not discharging any nutrient or chemical pollution, and does not use chemicals or antibiotics harmful to human or ecosystem health in the production processes,

4) uses native species/strains and does not contribute to "biological" pollution; but if exotic species/strains are used complete escapement control and recovery procedures are in place, and active research and development programs provide complete documentation and public information;

5) is integrated with communities to maximize job creation and training for displaced “sea workers”, and is a good community citizen; exporting to earn profits, but also marketing products locally to contribute to community development, and,

6) is a global partner, producing information for the world, avoiding the proprietary.

A new EU project titled, “Ecosystem Approach for Sustainable Aquaculture” is being led by Dr Kenneth Black of the Scottish Association for Marine Science. The project will consider the ability of indicators to discriminate between aquaculture and other anthropogenic sources of perturbation in the marine environment. Annual, national meetings with stakeholders will be held to allow two-way interaction ensuring the practical relevance of the work, and will insure that the “user community” achieves ownership of the project’s outputs. Objectives of the EU project are to:

- Identify quantitative indicators of the effects of aquaculture on ecosystems through a process of expert working groups, workshops, and meetings;
- Identify indicators of the main drivers of ecosystem change affecting aquaculture, including natural and environmental pressures;
- Assess sets of indicators using existing datasets – project partners collectively have extensive data archives – considering each in the context of appropriate selection criteria;

- Develop a range of tools, particularly models, that encapsulate best process understanding at a wide range of scales;
- Test models and indicators in a wide variety of field locations across Europe (~10 locations) that encompass major cultured species and technologies, and covering a wide spectrum of environment types, selected according to criteria developed during the project;
- Use the collected data to test and select the final "tool pack" of models and indicators, including appropriate decision support tools to guide users to effective implementation.

In France, a program on life cycle analysis is being developed based upon models developed originally for intensive farming (Papatryphon *et al.*, 2004). Indicators are based on the analysis of labour and energy required for each component of the production system, including the use of production factors, intermediate products, marketing and supply, as well as long-term investments for infrastructure and decommissioning. These indicators will allow the comparison of various production systems and the consideration of different technical solutions prior to decision-making.

Caffey *et al.* (2001) used a Delphi survey technique to develop sustainability indicators for aquaculture in the southeastern USA. The Delphi approach was started by the Rand Corporation in 1948 to develop strategy and forecasts during the Cold War (Sackman, 1975; Schmidt, 1997), and has been applied to a range of fields from agriculture (Walter and Reisner, 1994) to fisheries (Zuboy, 1981). The Delphi technique yielded 31 indicators of aquaculture sustainability: 12 environmental, 10 economic, and 9 social indicators (Table A7.3). Respondents identified two paramount environmental indicators: resource use and pollution. Resource use indicators included: conservation of land, energy, protein, water, and wetlands. Pollution (environmental externality) indicators included: reduction of chemical use, effluent BOD control, controls of ammonia-nitrogen, phosphorus, suspended solids, and use of non-native species in aquaculture. Top economic indicators were profitability, risk, efficiency, and marketing issues. Social indicators of top importance were job availability, compensation rates, benefits, and worker safety.

Discussion and Recommendations

Well developed and scientifically credible SIs are very important tools which can make monitoring, data collection and research enterprises, and communications efforts better organized and targeted, and thereby more cost effective. However, SIs for environmental and aquaculture management are still in the early stages of development; and we share the concern of Hammond *et al.* (1995) who question whether or not sustainability is a "bounded concept with measurable goals and objectives".

Sustainability is an overused word with abundant pedagogy but little practice. There has been much lip service given to the concept but little progressive action has been taken, especially in situations where there are time-worn political "turf wars", and in cases where there is a clear need for interdisciplinary actions but there is little scientific knowledge, or where there are clear winners and losers from environmental action. Sustainability cannot be defined in a stark "black/white" manner; or sustainable or not. Scaled comparisons between operating procedures are more valuable, e.g., "best" and "poor" practices and setting relevant benchmarks. Sustainability is an iterative process of improvement of management practices and procedures.

Bertollo (1998) expressed the concern that codes of conduct and guidelines for certifying sustainability in environmental management are much too complex. Recognizing this, Pullin *et al.* (2001) suggested a simple set of easily quantifiable indicators for sustainability in aquaculture:

- Biological: domestication, trophic level, nutrient/energy conversion,
- Ecological: footprint, emissions, escapes,
- Intersectoral: water-sharing, diversity, cycling, stability, and capacity.

Along with concerns about too much complexity, there is concern about the costs associated with monitoring multiple indicators that could be irrelevant to managers and the public. Useable indicators must be more than just a description of state and should have diagnostic properties that lead to some insights into processes taking place, and towards greater understanding of when things "go "wrong".

We have six recommendations concerning the development of acceptable sustainability indicators for aquaculture:

1) SIs must be of the highest scientific credibility and be accepted only after peer review of the chosen index, and analyses of precision, accuracy, reliability, and consistency are completed. Once accepted, SIs must be featured in monitoring and data management protocols.

2) At the outset it is important to discern the differences between "sustainability" indicators and "impact" indicators. Sustainability indicators should be able to track more than aquaculture's impacts on the environment - deterioration and recovery – and be able to monitor economic, social, and cultural externalities, as well as evaluate governance impacts of policies and regulatory measures on aquaculture. Once accepted, SIs need to be ultimately included in codes of best practices, decision support systems, and should be used in steering of the directions of aquaculture development by the authorities. They may also be used to monitor institutional changes and impacts of the policies (*ex ante* and *ex post*).

3) In the development of SIs for aquaculture it is important to develop them collaboratively and consider SIs from a managers' perspective. Managers are a critical link between the science community and the public. Collaborations between managers, scientists and the public should be formalized to facilitate rapid decision-making and communication. It is important that levels that exceed those which are accepted by the society are scientifically credible so that managers can determine who are the responsible parties and what actions are necessary.

4) We recommend that SIs for aquaculture be chosen that are not only scientifically credible but also simple and cost effective. An example is the simple monitoring of shellfish growth of animals deployed in cages in bays with and without finfish cage aquaculture in the Gulf of St. Lawrence, Canada (https://www-dev.gfc.dfo.ca/sci-sci/smn-rmm/index-e.jsp). This mussel growth index is a good SI for the Gulf in that it uses an important, keystone species that has a broad social and economic interest; this species has a wide distribution; and the monitoring results are indicative of aquacultures' impact on the health of the Gulf ecosystem.

5) SIs must be flexible enough to be adapted to the local environment in which they will be used. There is no chance that a single set of "generic" indicators may be universally applicable and used in all the situations in the aquaculture sector. In addition, SIs may be of use to address the interactions with other users of marine resources, locally or internationally because of the opening of global markets.

6) SIs must be able to detect the linkages between the 3P's - people, profit, planet - which calls for the development of a "sustainability indicator matrix". An example of this approach is given in Table 4 (this table needs to be completed) . Such a matrix approach will allow flexibility and be able to address the sustainability factors more comprehensively for any given situation. A regular implementation and evaluation of SIs will be necessary among the various actors assessing aquaculture developments, e.g., producers, policy makers, consumers, NGOs, suppliers, since aquaculture technologies and site locations are constantly evolving.

We would like to emphasize that SIs must be sustainable themselves. The production of information must be practicable at a low cost for the government, public, and the aquaculture sectors. Data from SIs must provide meaningful long-term data series. These time series will need to be housed in data management frameworks at the institutional level, but be universally accessible.

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Table A7.1. Definitions of Sustainability on the Web.

General Definitions	Web References
Meeting the needs of the present without compromising the ability of future generations to meet their own needs	www.afsc.org/trade-matters/learn-about/glossary.htm
A state or process that can be maintained indefinitely. The principles of sustainability integrate three closely interlined elements of the environment, the economy, and the social systems into a system that can be maintained in a healthy state indefinitely.	www.edo.or.blm.gov/infms/HTML/GLOSSARY/S.HTM
The ability to provide for the needs of the world's current population without damaging the ability of future generations to provide for themselves. When a process is sustainable, it can be carried out over and over without negative environmental effects or impossibly high costs to anyone involved.	www.sustainabletable.org/intro/dictionary/
A concept and strategy by which communities seek economic development approaches that benefit the local environment and quality of life. Sustainable development provides a framework under which communities can use resources efficiently, create efficient infrastructures, protect and enhance the quality of life, and create new businesses to strengthen their economies. A sustainable community is achieved by a long-term and integrated approach to developing and achieving a healthy community by addressing economic, environmental, and social issues. Fostering a strong sense of community and building partnerships and consensus among key stakeholders are also important elements.	www.ci.austin.tx.us/zoning/glossary.htm
The ability of a community or society to develop a strategy of economic growth and development that continues to function indefinitely within the limits set by ecology and is beneficial to all stakeholders and the environment.	www.thecorporatelibrary.com/Help/glossary/glossary.asp
The term originally applied to natural resource situations, where the long term was the focus. Today, it applies to many disciplines, including economic development, environment, food production, energy, and lifestyle. Basically, sustainability refers to doing something with the long term in mind, (several hundred years is sufficient). Today's decisions are made with a consideration of sustaining our activities into the long term future	ag.arizona.edu/futures/home/glossary.html
Sustainable development is the process of conducting business and commerce in a resource conservative and resource efficient manner such that operations do not compromise the ability of future generations to meet their own needs. The essential elements of this trend are the promotion and maintenance of business and community development strategies that lead to a better business environment in the future; one sustained by stable, healthful communities within a clean, safe environment. The operative concept underlying this growing trend is an emphasis on fostering community and business activity that is driven by long range goals, often met through pollution prevention.	www.mass.gov/epp/info/define.htm
The long-term health and vitality — cultural, economic, environmental, and social — of a community. Sustainable thinking considers the connections between various elements of a healthy society, and implies a longer time span (i.e., in decades, instead of years)	mapp.naccho.org/mapp_glossary.asp
Indicates that a plan, initiative or physical development project can be implemented and supported over time without depleting or adversely affecting the resources and	www.uvm.edu/~plan/masterplan/glossary.html

management capabilities available to it.	
Sustainability is an economic, social, and ecological concept. It is intended to be a means of configuring civilization and human activity so that society and its members are able to meet their needs and express their greatest potential in the present, while preserving biodiversity and natural ecosystems, and planning and acting for the ability to maintain these ideals indefinitely. Sustainability affects every level of organization, from the local neighborhood to the entire globe.	en.wikipedia.org/wiki/Sustainability
Economic development that takes full account of the environmental consequences of economic activity and is based on the use of resources that can be replaced or renewed and therefore are not depleted.	biology.usgs.gov/s+t/SNT/noframe/zy198.htm
The measure by which a human activity can be continued without relying upon limited resources, such as fossil fuels, or by leaving waste behind, and also giving nature the chance to replenish itself	www.ecohealth101.org/glossary.html
Definitions of Environmental Sustainability	Web References
The ability of an ecosystem to maintain ecological processes and functions, biological diversity, and productivity over time.	www.umpqua-watersheds.org/glossary/gloss_s.html
The use of ecosystems and their resources in a manner that satisfies current needs while allowing them to persist in the long term.	research.amnh.org/biodiversity/symposia/archives/seascapes/glossary.html
Meeting the resource needs of the present population without damaging the functionality of the area's ecosystem or its ability to meet the resource needs of future populations.	www.fairus.org/Research/ResearchList.cfm
Use of resources in a manner that allows the resources to be replenished by natural systems, as well avoidance of pollution that damages biological systems. Use of resources in such a manner that they will never be exhausted.	web-savvy.com/river/Schuylkill/glossary.html

Table A7.2. International/National Efforts Developing Coastal Environmental Indicators.

STATE/ORGANIZATION (DATE)	INDICATOR REPORTS
Australia (2001)	State of the Environment report includes a chapter on coasts and oceans
Canada (2003a,b; 2004)	Environment and Sustainable Development Indicators of the National Roundtable on Environment and Economy (2003a); National Environment Indicator Series (2003b); Federal-Provincial-Territorial Coastal and Ocean Indicators in Support of the Integrated Management of Oceans
USA (2001, 2002)	State of the Nation's Ecosystems; US National Coastal Condition
Global Programme of Action	On going
Organization for Economic Cooperation and Development	On-going in its PSR Framework
UN Global Environmental Outlook	On-going
Millennium Ecosystem Assessment	On-going
ICAM/UNESCO	ICAM Guidance on Use of Coastal Indicators Worldwide (UNESCO, 2003)
EU	Water Framework Directive

Table A7.3. Indicators Identified for Aquaculture Sustainability Using a Delphi Technique (Caffey *et al.*, 2001).

ENVIRONMENTAL	ECONOMIC	SOCIAL
Quantity of Land Used	Gross revenue	Local consumption of product
Quantity of Energy Used	Total variable production cost	Use of local inputs
Animal Fraction of Supplemental Protein Used	Fixed costs of production	Value of job benefits
Quantity of Chemicals Used	Overall profit	Worker safety
Quantity of Water Discharged	Return on investment	Local ownership
BOD of Effluents	Variability in annual profits	Wage levels
Supplemental Feed Protein Used	FCRs	Jobs/employment
Total ammonia nitrogen in effluents	Cost of regulatory compliance	Competition with local industries
Culture of non-native species	Per capita consumption	Perception of local aquaculture industry
Total phosphorus in effluents	Market outlets	
Production of natural wetlands		
Suspended solids in effluents		

TableA7.4. Example of a Sustainability Index Matrix for Mariculture Operations.

SUSTAINABILITY INDICATOR LEVELS	ENVIRONMENTAL	SOCIAL	ECONOMIC
High	High Benthic Quality Index (BQI)	High community participation; commitments to diversity; tolerance; humility; compassion; fellowship; pluralism; honesty; adherence to laws; discipline; investments in health; nutrition; education	Economic sustainability means making profit. High economic sustainability means work is on-going to quantify intangibles and common property resources (air, waters, oceans, etc.). Environmental and social costs are being internalized through new policies and valuation techniques.
Average	Good/Moderate BQI	Average investments in social programs	Average investments in internalizing environmental and social externalities
Low	Poor/Bad BQI	No investments in social programs	No investments in internalizing environmental and social externalities
References	Rosenberg *et al.* (2004)	Goodland and Daly (1996)	Goodland and Daly (1996)

Annex 8: An evaluation of 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

Introduction

The global demand for seafood continues to rise, and it is predicted that by 2030 nearly 50% of the world's seafood will come from aquaculture sources (Neori *et al.*, 2004). Systems ecology approaches are used to develop aquaculture production for the target species in a highly diversified, segmented manner, with numerous interconnections supplying inputs and outputs using local resources and recycled wastes and materials, planning for maximal job creation, and closing leaky loops of energy and materials that can potentially degrade natural ecosystems. The principles of ecological aquaculture are that it treats and recycles its own wastes rather than relying on natural environmental process and management process to mitigate cumulative environmental effects. It integrates people with technologies in new synergies to create new employment and biotechnical advances with a global view, integrating ecological issues and sharing technological information with innovation in the global marketplace.

Two major categories of animals are cultured intensively around the world: suspension feeders such as bivalves which feed directly on natural phytoplankton populations, bacteria and detritus; and species such as marine finfish and shrimp, which require an exogenous input of food for growth. Modern aquaculture systems are typified by intensive culture of a single species in open-sea net pens in coastal areas and in land based systems (ponds, tanks). There have been concerns about intensive aquaculture operations being feedlots (Wohlfarth and Schroeder, 1979), that are energy intensive (Weatherly and Cogger, 1977), producing nutrient pollution loads comparable to human sewage (Bergheim and Sivertsen, 1981; Bergheim *et al.*, 1982), and leading to accelerated eutrophication, harmful algal blooms, and unacceptable modification of benthic ecosystems (Beveridge *et al.*, 1991; Pullin *et al.*, 1993; Folke *et al.*, 1994; Costa-Pierce, 1997). An approach to mitigate the environmental impacts is by integrating fed aquaculture (finfish, shrimp) with inorganic and organic extractive aquaculture (seaweed, shellfish) whereby the wastes from one resource user becomes a resource (fertilizer, food) for the other.

At the farm level, the term integration can be understood under two main concepts:

- rearing various species in the same production unit;
- rearing a single species downstream from another;
- a combination of these two; rearing different species in parallel in different rearing units is not integration.

At a greater scale (e.g., an embayment), integration may address the optimisation of shared resources among various aquaculture users (e.g., shellfish or seaweed farms around fish farms).

In exploring the scientific literature regarding the co-culture of marine species, a range of terminology has been developed and used interchangeably to refer to this form of mariculture. These include:

- Polyculture;
- Integrated Aquaculture;
- Multi-Trophic Aquaculture;
- Ecological Aquaculture;
- Sustainable Aquaculture.

In this document, these terms may be used interchangeably to reflect the position and preferences of the international researchers, but should be regarded as comparable in our overview of the concepts, types and effectiveness and benefits of these integrated multispecies/multitrophic systems.

Environmental Benefits

Intensive fed aquaculture (finfish and shrimp) throughout the world has raised concerns about the environmental impacts of such mono-specific practices, especially where activities are highly geographically concentrated or located in suboptimal sites whose assimilative capacities are poor and consequently prone to being exceeded. Traditional methods of treating aquaculture effluent have been built on technological solutions such as mechanical separation of solid particles using screens, sedimentation, filtration (Cripps, 1994) and biological filtration of dissolved nutrients. Integrated farming methods are built on ecological engineering practices, where "extractive" (i.e., bivalves, macro algae) and "fed" (salmon, sea bream) species are grown simultaneously, and have been proposed as a means for recycling the nutrients and particulate wastes from fish cage farming and land bases farms.

All of the compounds in fish food as well as the by-products of metabolism are potential waste products, and are lost via two pathways. Organic carbon and nitrogen compounds can be lost directly (due to uneaten food pellets), and indirectly (due to faeces), (Gowen and Bradbury, 1987), while other nitrogenous wastes (ammonia and urea) as well as phosphate, are dissolved into the water column surrounding the farms. It is the potential ability of these compounds to cause hypernutrification and eutrophication (Folke and Kautsky, 1992), particularly in the case of poorly sited and managed marine cage aquaculture, in both the benthic and pelagic realms that is of concern. Although some studies of cage aquaculture have indicated that ecological impacts may be localized and reversible by fallowing (Stewart, 1998), the management and treatment of open cage aquaculture effluent remains an important issue.

Poorly sited and managed marine cage aquaculture operations have caused environmental impacts, but assessments of impacts have too often been based upon out-dated literature, scientific misinterpretation, and advocacy. Review of studies of benthic impacts of cage aquaculture has shown ecological impacts to be localized and reversible by fallowing (Stewart, 1998, Hargrave, 2003). After extensive studies, the Net Pen Advisory Work Group of the Washington Department of Ecology (WDOE) found that benthic impacts of salmon farming in Puget Sound was limited to within 30 m of the net pen perimeter, and that impacts were reversible by fallowing. Based upon their data the WDOE decided to mange salmon pens by allowing a sediment impact zone within a 30 m of the edges of the cages. Outside of this perimeter, water quality and benthic "performance standards" would have to be met (Rensel, 2001). However, additional research needs to be conducted since very few data exist to date on the long-term assimilative capacity of benthic communities in different climatic regions. For example, Angel *et al.* (1992) found that organic matter decomposition in sediments under fish cages in the Gulf of Aqaba may be 3–4 times greater than in temperate waters.

In concept, the design of an integrated aquaculture system will provide a balance of biological components (co-cultured species) such that the production of wastes from one component is used (extracted, ingested) in a manner that optimizes the growth of a second, the second providing inputs to a third, etc. In a well-balanced system this relationship provides the environmental benefits associated with polyculture, and is the basis of definitions such as Sustainable, or Ecological Aquaculture.

Initiatives on the east coast of Canada (New Brunswick) have recently evaluated the performance of mussels (*Mytilus trossolus*) and large macrophytes (*Laminaria*) cultured within the infrastructure of an open net-cage salmon (*Salmo salar*) aquaculture facility. Chopin *et al.* (1999, 2001) and Neori *et al.* (2002) demonstrated that these integrated species perform significantly better within the influence of the salmon net-cage systems as compared with a monoculture arrangement removed from the apparent effluent effects of the finfish system. In contrast, a study in Tasmania, Australia (Cheshuk *et al.*, 2003) indicated that mussels (*Mytilus planulatus*) grown within 70 meters of a salmon (*Salmo salar*) farm revealed only very minor improvements in growth (shell height) and condition over the 14-month grow-out period. Stirling and Okumus (1995) also showed slight increases in mussel culture performance, grown at two salmon farm sites in Scotland, and suggested that enrichment of the seston field by organic material from the salmon farm was likely contributing to this observed elevation in growth. Cross (unpublished) observed that oysters (*Crassostrea gigas*) and scallops (*Patinopectin yessoensis*) showed neither a positive nor negative growth change as a result of co-culture with Pacific (*Oncoryhnchus tshawytscha)* or Atlantic *(Salmo salar*) salmon.

Although the combination of species proposed for a Multi-Trophic Aquaculture (MTA) system will determine to what degree the transfer or organic waste materials are effectively used among the co-cultured species, the literature has suggested that these direct environmental benefits are highly variable among systems and may in fact represent a smaller benefit in open marine systems than anticipated. However, the environmental benefits of MTA are not constrained solely to the direct assimilation of waste constituents among the co-cultured species, but will also be achieved indirectly through the physical design/configuration and orientation of such a system with respect to adjacent, and potentially sensitive marine habitats.

Social Benefits

The social benefits associated with the development of marine integrated aquaculture include: (i) optimizing potential culture opportunities in jurisdictions that are constrained by available space (e.g., New Brunswick, Canada; small EU countries); (ii) provision of development opportunities in remote coastal regions that are otherwise constrained by operational logistics (e.g., north coast of western Canada, southern coast of Chile, north coast of Norway); and/or (iii) provision of product diversification at the coastal community level that could stimulate the development of a larger and more diverse secondary industry support system.

In southern Europe, where coastal zones have been already heavily impacted, the restoration of abandoned wetlands and the optimal use of existing ponds is a coastal zone management issue. Maintaining these sites is costly and cannot be handled by public funds only. The Common Agriculture Policy and Common Fishery Policy, requires primary users of the natural resources (e.g., agriculturists, fishermen, aquaculturists) to implement the ecosystem approach in the management and conservation of the environment and landscape. It considers polyculture as utilization of these areas that could provide restoration at the lower cost for the society.

Economic Benefits

While most of the scientific community assessing the potential for Multi-Trophic Aquaculture agree that this approach has considerable merit in terms of environmental benefits (at least in theory), the question remains: "*why has this not yet been widely accepted and developed at the commercial level*?"

It is clear that while there is *potential* for MTA, commercialization is based on an evaluation of not only opportunity, but of economic risk in terms of associated capital/operational costs, performance certainty, impact and integration of multi-products to existing markets and sales pathways, personnel requirements, and profitability. The widespread commercial development of MTA by industry has not yet occurred most likely due to one or a number of these business uncertainties. The remaining challenges facing future research and development of these systems include initiatives that will address the practical aspects of commercial-scale

MTA facilities, and to offer results that could be assessed by the investment community that would allow these development risks to be properly considered.

The economic benefits offered by integrated systems was evaluated from two corporate development perspectives: (i) modification of existing finfish culture sites to accommodate shellfish; and (ii) using an integrated finfish-shellfish approach in remote coastal areas that might otherwise be logistically impractical and cost-prohibitive for a typical shellfish producer to consider for development. Factors contributing to the cost-effectiveness of these hypothetical integrated aquaculture systems included the ability to:

- Share on-site support infrastructure (e.g., accommodation, working platforms, system anchoring grid);
- Share transportation linkages (e.g., feed delivery for fish, return with shellfish product; crew change logistics);
- Share site staffing (overlap of duties to take advantage of quiet periods in each of the production cycles); and
- Share and hence reduce marine vessel requirements for on-site husbandry uses.

Integrated Aquaculture Examples

Table A8.1 provides a summary of the current research and pilot-scale integrated aquaculture facilities. Many of these are based on small experimental systems, within the RandD process, and may be of questionable sustainability and economic viability.

Four examples of commercial-scale and/or projects in development at pilot-scale are described below.

The following are four examples of pilot or commercial scale MTA project. Selected results specific to each of the projects are presents. It is assumed that the general environmental and socio-economic benefits described above are applicable to these examples.

MTA in the Mediterranean

In the Mediterranean, integrated aquaculture is practiced by a few countries. This could be explained by the fact that integration is easier to develop from extensive systems where they do exist than from intensive ones. To our knowledge, no integrated systems occur in Europe north of the English Channel. These systems represent a range of intensification from the extensive to the intensive forms (Table A8.2).

Extensive production of fish in Lake Quarun in Egypt (El Gayar, 2003) The technique is based on restocking a salt lake with various juvenile species which are mainly caught from the wild. Production in the lake is estimated at 23 000 tons, and is extensive (yield of 150 kg/ha per year). The main species produced are mullets (all species), seabream, seabass and shrimp. Adjacent earthen ponds are used for rearing mullet juveniles, using fertilisers to enhance their productivity. The major threat to sustainability is the capture of wild fry, particularly mullet, whose reproduction cycle is not yet closed. Mullet production in Egypt is around 160 000 tons per year.

Extensive production of fish in Valliculture in Italy

Around 43 000 ha of earthern ponds in brackish waters are cultivated, mainly in the Po River delta. These areas produce 3000 tons of mullets, 1000 t of seabream, 1000 t of seabass and 200 tons of eels per year. Seabass and seabream fry come from hatchery production, while mullet and eel are from the wild. The main income in these areas is more from tourism and hunting rather than from aquaculture. Nevertheless, aquaculture makes the enterprise profitable. A major threat for these systems is the predation by birds (cormorants). A single individual can eat 100 to 400 g of fish per day.

Semi-intensive production of fish in Spain (Andalucia) and Portugal

The production system is a combination of various systems based on levels of intensification. Extensive, semi intensive and intensive technologies are mixed to produce seabream, seabass, mullets, eel, sole and shrimps: 60% of the 6700 tons annual production is from the semi-intensive units, the bulk of it being represented by sea bream from land based hatcheries. The remaining is intensive production (34%) and extensive (300 tons, 6%). Sole, mullets, shrimp and eels are produced in the extensive system. One advantage of this system is the water reuse from the more intensive part to the extensive one, thus reducing the need for water. It has been observed that the nutrient and organic matter contents in the effluent from the intensive part sustain the production of worms (for soles) and other preys in the extensive ponds. Attempts are undergoing to cultivated clams (*Tapes decussatus*) in the same ponds. Some of these farms charge tourists for admission (aquatourism).

Semi intensive production of shrimps and oyster in Southern France

The level of production is very low (60 tons of *Paeneus japonicus* per year), but is sustainable, having been in operation for 20 years. Five years ago oysters (*Crassostrea gigas*) were incorporated within the same ponds. Oysters are able to utilise the phytobenthos that is resuspended by shrimp foraging activity. By increasing the income through aquaculture the combined system has proved to increase the economic sustainability of the farm.

MTA in Western Canada

Cross (unpublished) recently completed a 3-year research program that examined the environmental, social and economic potential of Multi-Trophic Aquaculture in coastal British Columbia. This research assessed the interactions between salmon (*Oncoryhnchus tshawytscha, Salmo salar*) and shellfish (*Patinopectin yessoensis, Crassostrea gigas*), with a focus on the possible water quality and hence seafood safety issues associated with co-culture of these species. The program results are also being used in the development of a commercial facility on the west coast of Vancouver Island, British Columbia.

Environmental Benefits of MTA in Western Canada

Organic waste dispersion and accumulation patterns were examined for a 2500 MT salmon aquaculture facility using DEPOMOD (validated through field data). The facility was then re-configured to a conceptual finfish-shellfish MTA system with similar fish production, but with an integrated shellfish component. A subsequent model evaluation of the organic waste 'foot-print' revealed an order-of-magnitude decrease in flux values, and suggested an environmental benefit in terms of reduced benthic impact, increased assimilative capacity of these wastes, and long-term operational sustainability.

Socio-Economic Benefits of MTA in Western Canada

With the development of an integrated finfish-shellfish aquaculture system based on a modified (stretched) 12-cage steel net-cage facility, Cross (unpublished) estimated that the capital and operational cost-savings realized by the shellfish component of the system (40 rafts) to be between 66 and 79% of that of an independent shellfish operation of similar size. Furthermore, his projections suggested that profitability of the shellfish aquaculture component ranged from 0.8 – 20% (net profits), compared to that of an independently operated shellfish operation of similar size (in a remote location) that would realize a net loss and that these margins (either negative or positive) would vary dependent upon distance from an operational base (port).

In remote coastal areas operational efficiencies become critical in determining the economic viability of a proposed shellfish aquaculture facility, and the development of an MTA system provides the opportunity to capitalize on the infrastructure and operational activities/schedules available through the other culture components (e.g., finfish). In particular, transportation costs (e.g., for crew, supplies, seed, harvest product) represents a significant, and usually limiting factor for developing shellfish in remote regions.

Further operational efficiencies, and hence potential profitability, were identified in an evaluation of integrating shellfish with existing finfish operations. The assessment assumed that a finfish company that maintained 16 salmon farm sites might include 7 sites that could support an MTA system, and as a result realize the benefits associated with the management of multiple production sites (economies of scale).

Integrated Mariculture Development in Western Canada

The results of this research initiative, and ongoing industry discussions, are currently being applied to the development of a privately funded production/research facility on the Canadian west coast. The proposed *Pacific Mariculture Research Station* will comprise an integrated raft and steel netcage system, with unique design features to support ongoing, commercial-scale research efforts for combining a variety of mariculture species (e.g., finfish, bivalve mollusks, macrophytes, urchins, abalone). This facility is presently under construction and will support 28 finfish netcages, 20 invertebrate raft modules, and approximately 1,000 metres of integrated longlines for a macrophyte component. The primary goal of this demonstration/research facility is to address outstanding commercialization issues related to temperate Multi-Trophic Aquaculture development, and as such to provide access to commercial-scale infrastructure for researchers in this field of mariculture. As a licensed and *bona fide* aquaculture production site, the PMRF will also move towards production profitability, operational sustainability, and to the transfer and further commercialization of associated technological innovations by the aquaculture industry at large.

Integrated Aquaculture in Eastern Canada

An experimental commercial scale project in the Fundy Isles Region, New Brunswick, Canada on the feasibility of the integrated multispecies aquaculture by combining inorganic extractive aquaculture of the kelp, *Laminaria saccharina*, and organic extractive aquaculture of the blue mussel, *Mytilus edulis*, with the fed aquaculture of salmon, *Salmo salar* is in progress. The project in co-operation with the Atlantic salmon Aquaculture industry and is investigating the incorporation of mussel and kelp culture facilities on existing commercial salmon culture stities. Food safety and physical/chemical modelling (especially of the oxygen budget) and the socio-economic studies are included (Chopin *et al.*, 2002, 2003, 2004).

Environmental Benefits of MTA in Eastern Canada

The following results from these studies would suggest that the mussels and kelp are utilizing the wastes from the salmon culture to their benefit as well as the environment. Kelps grown in the vicinity of salmon farms increased their growth rates by 46 % in comparison to kelps grown at reference sites. Blue mussel, *Mytilus edulis*, was developed to show that mussels are not only capable of capturing excess food particles from the fish farm but also increase their feeding rates in response to the presence of these particles. Seston levels at salmon farms are elevated by a factor of 2 to 4 over ambient levels and are of very high quality (up to 90 % organic). Enhanced growth rates at farm sites (50 % more than that of mussels at reference sites) and accelerated production times to commercial size (approximately 18 months from socking) reflect this increase in food energy, as mussels ingest fish food particles with approximately the same efficiency as phytoplankton species. None of the therapeutants used in the Bay of Fundy (oxytetracycline and emamectin benzoate) have been detected in kelps or mussels collected from the integrated sites

Socio-economic Benefits of MTA in Eastern Canada

The logistics of the kelp and mussel culture portion of an integrated operation appear to fit well with the day-to-day operations of a regular salmon farm. Mussel seed acquisition was not an issue as the cleaning of the nets provides an abundant source of juvenile mussels.

A survey of aquaculture attitudes found that the general public is more negative towards current monoculture practices and, although relatively unfamiliar with the concept, feels positive that integration would be successful.

MTA in Israel

Description of a land based pilot scale facility aiming at integrating fish-shellfish-algae - The most promising developments in this respect have been realized in Israel using seabream as the fish species and *Ulva* for the seaweed, which ultimately feeds abalone (*Haliotis discus*) or urchin (Shpigel, 1996). Abalone fed with *Ulva* are reared on inflowing water, then seabream are reared in intensive circular tanks, and ultimately *Ulva* (fed to abalone) are cultivated in raceways using effluent water from seabream, which are downstream from the sedimentation tank. Water from *Ulva* can be re-used for seabream rearing. The main features of the system are summarized (Table A8.3).

Contrary to rearing various species in one polyculture system, the integration of various monoculture through water transfer alleviates one of the deficiencies of the former: a smaller yield of each organism. This is made possible because the fish and the algae have opposite effects on the water quality i.e., CO2, O2, dissolved nitrogen and phosphorus, dissolved heavy metals, pH.

Environmental Benefits of MTA in Israel

The nitrogen budget is very promising since the uptake efficiency by *Ulva* was about 90% of the dissolved nitrogen on an annual average, at a ratio of 3–5 g of nitrogen per square meter per day. Instead of disposing 175g of nitrogen per month (for 10 tons of fish production at an average ammonia concentration of 12 $mg.l^{-1}$) in the environment, the algal treatment allows only 25g (2 $mg.l^{-1}$ of ammonia) to enter the water body (to be compared to the 5g from the inflowing water). The calculation made by Neori *et al.* (2000) indicates that to depurate nitrogen, a farm producing 1000 ton of seabream per year would need around 15 ha of *Ulva* biofilter and 7ha of tanks supporting the production of 660 tons of abalone, which is however, more efficient than sea urchin in the same context.

This system is well adapted to conditions in Israel (particularly temperature and light) but, these results have to be taken cautiously for any further extension. Comparable pilot scale experiments in southern France (Deviller *et al.*, 2004), in less favorable conditions, the seaweed growth is susceptible to seasonal variations. In more northern regions, the most probable developments would occur by using phytoplankton for bioreactors and filtering bivalves for secondary production (Hussenot, 2004).

Socio-Economic Benefits of MTA in Israel

Even if the investment breakdown is equally shared between the three stages, it appears that the main revenue comes from the abalone production. Based on the figures of Table A8.3, the income from the farm would be 1.05 million Euros from the sea bream and 6.5 million Euros from the abalone. The farm would be barely profitable without producing abalone, the addition of this unit raised the expected profit from nearly zero to 2.5 million Euros. At any case, labor costs are critical to this system, mainly for the abalone unit: the expected needs in work force are 10–12 permanent employees. In addition the capital to be invested is very high. Again based on the figures from Table A8.3, the initial investment would be 1.3 million euros.

These figures have to be compared to the global revenues from a similar cage farm. According to Neori *et al.*, (2004), the production costs are comparable if the cost incurred for water treatment would be added in the form of taxes (according to the polluter-pays principle). From these results, a commercial farm has been put in operation in 2004.

Clearly it is a matter of governance which will decide whether these types of systems will be developed, The potential negative effects of releasing nutrients in the environment has a cost and a risk analysis will be required.

Summary

MTA represents a global aquaculture sector of growing interest and potential development. Although much of this interest has been expressed through ongoing research initiatives, there has been some movement towards commercialization of these opportunities. The advantages and disadvantages of integrated mariculture, based on our assessment of the environmental, social and economic considerations for this sector are:

Advantages:

- Reduction in net effluent discharges;
- Shared operational resources is more cost-effective thus increased profitability;
- Production intensification without environmental degradation;
- Diversification of production- market potential;
- “Sustainable” approach to aquaculture- public awareness benefits;
- Development of aquaculture in remote coastal communities (economies of scale);
- Improvement to overall water quality may reduce likelihood of disease outbreaks.

Disadvantages:

- Technically more complex- higher capital costs;
- Greater scope of technical expertise required to operate system;
- Handling (e.g., grading, harvesting) of individual species components more difficult;
- Monitoring and control of disease organisms is more difficult (potential reservoirs?);
- Can require extensive areas for development;
- Maintaining optimal environmental conditions (e.g., temperature, salinity) for multiple species;
- Water quality effects among integrated components require management (e.g., antibiotic use).

Recommendations

There are many technical details of integrated mariculture that need to be addressed through further research. In terms of the management of pond-based integrated aquaculture systems these efforts include, for example, the development of:

- Algal control strategies;
- Nutritional strategies, including fertilization and supplemental feeds (micoralgae, zooplankton, artemia, polychaetes);
- Methods for mass production of juveniles for system stocking; and
- Optimal fish stocking and fertilization (through modelling).

With respect to open, coastal integrated aquaculture (intensive or extensive), similar such research and development initiatives need to be completed. These comprise, for example:

- Evaluation of the efficacy of these systems in terms of environmental impact mitigation;

- Determining an appropriate number and species composition of trophic components (balancing energy/organic materials transfers);
- Identifying and developing management approaches for potential water quality interaction effects (e.g., antibiotic residues); and
- Providing recommendations for changes to regulatory frameworks to accept integrated aquaculture development.

However, to successfully transfer the concept of integrated aquaculture to industry the technical challenges associated with the practical aspects of commercial-scale facilities must be addressed, and these results presented in a context that could be assessed by the investment community that would consider these development opportunities. Future challenges should consider pilot-scale testing of integrated aquaculture systems to permit these issues to be addressed accordingly.

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Table A8.1: Integrated mariculture systems – experimental and pilot-scale.

Water Based Systems	References
Two Phyla Systems	
Sea cucumber to process fish wastes	Ahlgren (1998)
Abalone-seaweed combination	Benson *et al.* (1986)
Grey mullet in bottom cages underneath commercial sea bream cages	Angel *et al.* (1992), Katz *et al.* (1996)
Cultivation of seaweeds (*Laminaria saccharina, Nereocystis luetkeana*, *Gracilaria*, *Porphyra*) with salmon cage aquaculture	Ahn *et al.* (1998); Chopin *et al.* (1999, 2001); Buschmann *et al.* (1994, 1995, 1996, 2001); Chung *et al.* (2002); Troell *et al.* (1997, 1999a, 1999b); Petrell and Alie (1996)
Salmon (salmo salar), sea urchin (	
Three Phyla Systems	
Salmon (*Salmo salar*), mussels (*Mytilus edulis*), seaweed (*Laminaria saccharina*)	Chopin *et al.* (2002, 2003, 2004)
Land Based Systems	
Two Phyla Systems	
Integrated shrimp-oysters	Wang (1990)
Integrated Shrimp-scallops	Walker *et al.* (1991)
Integration of fish culture (sea bream, salmon) with seaweed (*Ulva, Gracilaria, Laminaria)*	Cohen and Neori (1991); Krom *et al.* (1995); Jimenez del Rio *et al.* (1996); Neori *et al.* (1991, 1993, 1996, 2000); Buschmann *et al.* (1994, 1996); Martinez and Buschmann (1996); Haglund and Pedersen (1993); Subandar *et al.* (1993); Pagand *et al.* (2000); Vandermeulen and Gordin (1990)
Integration of abalone and sea urchins	Miller (1989)
Integration of abalone and seaweeds (*Gracilaria, Ulva, Palmaria*)	Neori *et al.* (1998); Evans and Langdon (2000)
Integration of fish (turbot, sea bass, sole) and bivalves (clams, oysters)	Jara-Jara *et al.* (1997); Lefebvre *et al.* (2000)
Integration of shrimp and seaweeds (*Gracilaria, Ulva*)	Danakusumah *et al.* (1991); Nelson *et al.* (2001); Phang *et al.* (1996)
Three Phyla Systems	
Integration of shrimp, oysters and seaweed (*Gracilaria edulis*)	Jones *et al.* (2001)
Integrated shrimp- fish (mullet)-oysters	Sandifer and Hopkins (1996)
Integrated culture of fish (sea bream), bivalves (*Crassostrea gigas, Tapes semidecussatus, Haliotis tuberculata*) and seaweed (*Ulva, Gracilaria)*	Shpigel *et al.* (1993, 1996); Neori (1996); Neori *et al.* (2000)
Four Phyla Systems	
Integration of fish-oysters-sea urchins and seaweeds	Chow *et al.* (2001)

Table A8.2: Classification aquaculture by degree of intensity (Hussenot, 2003).

	DESCRIPTION	TYPICAL AREA (PER PRODUCTION UNIT)	PRODUCTIVITY (PER YEAR) STANDING BIOMASS (KG/M3)
Extensive	Traditional extensive culture used for eels (*Anguilla* spp.),grey mullets (*Mugilidae*), sea bass, sea bream	1 – 100 ha	t/ha 0.1 – 0.5
Semi intensive	Semi-intensive earthen ponds producing sea bass or sea bream	0.1–1 ha	20–50 t/ha 1.0 - 4.0
Intensive	Unit Intensive grow-out of sea bass and sea bream in concrete tanks or ponds covered by greenhouses or inflated structures.	0.01–0.3 ha	200–400 t/ha 5.0 – 30.0

Table A8.3: Production from a pilot scale integrated multispecies aquaculture site in Israel (Neori *et al.*, 2004).

ORGANISM	POND SIZE RATIO/HA	YIELD (MT Y^{-1})	YIELD (KG M^{-2} Y^{-1})
Seabream	1	265	22
Ulva	3.5	2215	64
Abalone	1.85	185	10
or Sea urchin	2.75	275	10
Total	*6.3*	*450*	*30*

Annex 9: Additional Recommendation and draft Terms of Reference

1. The WG recommends that the draft technical report on “Chemicals used in Mariculture” (reviewed at WGEIM 2003) be passed to ACME for publication in the *ICES Cooperative Research Report* series.

Justification: The use of chemicals as therapeutants, disinfectants, etc., in mariculture remains of significant concern to the industry, regulators, and the public. This second edition of *ICES Cooperative Research Report* No. 202 brings the report up to date, and should prove to be a valuable reference work. The update was overdue as chemicals and regulations have drastically changed during the past few years and requests for current information on the use of chemicals have been from industry, regulatory agencies, and NGOs. The report includes detailed technical information concerning the chemicals used, their specific purposes, and references to environmental implications of their use. In particular, the report discusses in detail the significance to the environment of the use of antibiotics, and makes observations on changes in the pattern of use of antibiotics and sea lice control treatments as national fish cultivation industries mature.

Working Group on Environmental Interactions of Mariculture [WGEIM] will (provisionally) meet from 24–28 April 2006 (Chair: F. O’Beirn, Ireland) in Narragansett, Rhode Island, USA to:

a) finalise a joint publication with the GESAMP WG 31 on the aquaculture risk analysis methodologies, comprising an overarching protocol document and a number of worked examples including the potential impacts of escaped non-salmonid farmed fish (cod, sea bass, sea bream, halibut, turbot);

b) provide an update on developments in implementation of the WFD, the European Marine Strategy, the EU Strategy for sustainable aquaculture and related developments, and assess their implications for mariculture;

c) to finalise arrangements for a theme session on carrying capacity models for shellfish cultivation to be held at ICES ASC 2006/7;

d) evaluate examples of sustainability indices proposed for mariculture operations and provide specific recommendations on utility of proposed indices in light of suitability criteria listed in WGEIM 2005 report;

e) evaluate integrated culture systems focusing upon the efficacy of these systems in terms of environmental impact mitigation and provide recommendations on appropriate research avenues as well as changes to regulatory frameworks to accept integrated aquaculture;

f) provide an update on the sustainable supply of components of formulated feeds for finfish aquaculture;

g) investigate the hazards associated with mariculture structures in terms of habitat change/modification and assess their potential for accommodating invasive/nuisance species in a system - proposed in consultation with WGITMO;

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

Supporting information

Priority:	WGEIM is of fundamental importance to ICES.
Scientific Justification and relation to Action Plan:	In order to foster a sustainable development of coastal and marine aquaculture, there is a need to diversify production and to cultivate new species. A pro-active approach is required to avoid mistakes made previously when salmonid farming was developing. Mitigation strategies based on sound scientific criteria in relation to the species under consideration need to be prepared at an early stage of

	development. Studies would have to consider the status of the natural stocks in the area, the potential genetic, trophic and behavioural interactions, and, foremost and specifically, the development of methods for recovery of escaped fish in the event of large-scale escapements. This subject seems to be of particular importance for non-migratory fish stocks with small, localised populations (e.g., sea bass and sea bream), or migratory species with different migratory patterns than salmonids (e.g., cod, halibut, turbot, and wolfish, and other species). The report will include an overall risk assessment template and will recommended mitigative strategies with some worked examples of the aforementioned finfish species. Work being considered for shellfish topics will continue to be cross-referenced and discussed with WGMASC intersessionally. In addition, WGEIM have greatly benefited from inputs of the GESAMP WG31. 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. The current document will be review intersessionally by GEASAMP WG31 in autumn 2005 and finalised in WGEIM 2006. The Water Framework Directive will determine the direction of water quality regulation and improvement in the EU over the next 10–20 years. The coincidence of major new policy initiatives in both industrial development strategy and environmental quality presents European aquaculture with a unique set of opportunities and risks. The EC policy on Sustainable Aquaculture sets a new context for the aquaculture industry in the EU. It holds out the possibility, among other things, that Integrated Coastal Zone Management will become the normal approach to the management of the aquaculture development, and that new tools and processes will arise from the new policy. The group will continue to monitor developments in these areas and assess their implications for mariculture. Interest in shellfish cultivation is expanding rapidly in many ICES countries. However, with this interest is an attendant risk of increased conflicts with other resource users and exceeding carrying capacity in the growing areas. The last significant international symposium on shellfish carrying capacity was held around 6–8 years ago. The purpose of this agenda item is to forward plans for a theme session at the ICES ASC 2006/7 in cooperation with the WGMASC. The session will focus upon carrying capacity research in marine shellfish culture areas with particular emphasis upon how ecological models interact with physical, production and socio-economic models. Sustainability indexes have, among other uses, been offered as a methodology to integrate large amounts of scientific information to underpin management 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. 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. 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.

	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. Cearly 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.

Annex 10: Action Plan Progress Review

Year	Committee Acronym	Committee name	Expert Group	Reference to other committees	Expert Group report (ICES Code)	Resolution No.		
2004/2005	MARC	Mariculture	WGEIM		2004\F:04	2F04		
Action Plan	Action Required	ToR's	ToR	Satisfactory Progress	No Progress	Unsatisfatory Progress	Output (link to relevant report)	Comments (e.g., delays, problems, other types of progress, needs, etc.
No.	Text	Text	Ref. (a, b, c)	S	0	U	Report code and section	Text
2.5, 2.6, 3.3, 4.6, 4.7, 6.3	Please see action item below	Prepare a publication on the "state of knowledge" of the potential impacts of escaped aquaculture marine (non-salmonid) finfish species on local native wild stocks and complete the risk analyses of escapes of non-salmonid farmed fish	a)	S				This term of reference has been a major subject for WGEIM since 2003. It has progressed very well since last years meeting and the hope is that a publication on the overall templates and some select species will be finalised in 2006.
2.10, 3.3, 4.6, 4.7	Please see action item below	Work with GESAMP WG 31 to develop aquaculture risk analysis methodologies;	b)	S				See above comments
2.5, 3.3, 4.6	Please see action item below	Update the report on developments in implementation of WFD and EU Strategy for sustainable aquaculture;	c)	S				##
2.12	Please see action item below	Evaluate the recent developments over the last 5 years in carrying capacity models for shellfish with a view to proposing an ICES theme session or co-sponsored symposium in this area;	d)	S				This review has identified some important considerations in the development of carrying capacity models for shellfish culture and will be progress jointly with WGMASC.
2.6, 3.7, 3.11,	Please see action item below	Consider and evaluate the possibility for developing a "sustainability index" concerning environmental interactions of mariculture;	e)	S				This important ToR consisted of a review of the material with the goal of continuing to monitor developments in this area in light of criteria selected by the group
2.6, 3.11	Please see action item below	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.	f)	S				As above this ToR consisted of a review of current developments in the field of integrated culture.

Action Plan Nos. to be	
2.5	Assess and evaluate the genetic consequences of human-induced selective factors, whether intentional (such as selective breeding for mariculture) or unintentional (such as selective effects of fishing). [MARC/LRC/ RMC/DFC/ACE/ACME]
2.6	Evaluate and assess the intra- and interspecific interactions of wild and farm-reared stock as well as disease and genetic interactions. [MARC/LRC/DFC]
2.10	Evaluate and increase knowledge on the potential impacts of intentional and accidental introductions of non-native species and their vectors of introductions. [LRC/MHC/MARC/DFC/ACFM/ACME]*
2.12	Evaluate and increase knowledge of the effects of human activities on the productive capacity of estuarine and freshwater habitats of diadromous fish. [MHC/OCC/MARC/BCC/DFC]
3.3	Develop a framework for an integrated evaluation of the impacts of human activities in the coastal zone, (e.g., mariculture, dredging/extraction, building structures), as an aid to coastal zone management. [MHC/MARC/RMC/OCC/DFC/ACE/ACME]*
3.7	Evaluate and improve analytical tools for quantifying the consequences of habitat alterations, including enhancement and mitigation measures, for conservation and rebuilding of diadromous stocks. [RMC/LRC/MARC/BCC/MHC/DFC/ACFM]
3.11	Evaluate information on technological change in mariculture, including the utilisation of new species, with particular emphasis on the consequences for production and the environment. [MARC/ACME]
4.6	Develop document guidelines for the preparation of Environmental Impact Assessments, and appropriate monitoring programmes. [MARC/MHC/ACME/ACE]
4.7	Review issues of sustainability in mariculture, including interactions between mariculture and other users of resources in the coastal zone, and between cultured and wild stocks. [MARC/DFC/ACME/ACE]
6.3	Encourage the production of high-quality scientific publications by ICES through a coordinated publications policy, involving continuous review of ICES scientific output and proactive support for its publications through diverse routes. [Publications Committee (PUB)/CONC/all Science Committees]