ICES WGEIM REPORT 2010

SCICOM STEERING GROUP ON HUMAN INTERACTIONS ON ECOSYSTEMS

ICES CM 2010/SSGHIE:08

REF. SCICOM, ACOM

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

29 March–2 April 2010

Galway, Ireland

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

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

H. C. Andersens Boulevard 44–46
DK-1553 Copenhagen V
Denmark
Telephone (+45) 33 38 67 00
Telefax (+45) 33 93 42 15
www.ices.dk
info@ices.dk

Recommended format for purposes of citation:

ICES. 2010. Report of the Working Group on Environmental Interactions of Mariculture (WGEIM), 29 March – 2 April 2010, Galway, Ireland. ICES CM 2010/SSGHIE:08. 58 pp.

Contents

Executive summary

The meeting (Chair: Chris McKindsey) was held on 29 March–2 April 2010 at the Marine Institute in Galway, Ireland, and was attended by 7 participants from 5 countries. It had two objectives (1) to have a joint meeting with the WGMASC to discuss topics of mutual interest, increase collaboration, and reduce overlap between the two groups, and (2) to work on the Terms of Reference. The ToRs were addressed separately, followed by plenary sessions. Because of limited time due to holding a joint meeting with the WGMASC, that half of the participating members were new to the EG process, and the work involved in providing OSPAR advice (ToR g), it was decided that only a selected number of ToRs would be addressed (ToRs a, c, and g). That being said, 3 participants who were to work on ToR c could not attend the meeting at the final minute and thus this ToR was also postponed. Although not addressed directly, information for the SSGHIE on potential and current contributions of the WGEIM for the SICMSP and for plans to collaborate with the WGMASC on similar issues were discussed in the context of the joint meeting with the WGMASC and are reported within the deliberations (ToR i). Because of the timely nature and joint interest by the two EGs, the Bivalve Aquaculture Dialogue, a WWF certification process for best practices for bivalve aquaculture, was also discussed and joint comments by the EGs are included as a final ToR (ToR j).

ToR a) The issue of sustainability of mariculture activities and indices to evaluate them (sustainability indices) has been addressed by the WGEIM and other EGs and groups for a number of years. Such reviews most often focus on impact indicators whereas sustainability indicators include social factors such as what is deemed to be acceptable by all stakeholders and consider other activities in the same area within the context of ICZM. Further, both positive and negative benefits of the activity must be considered. WGEM members will work in the intersession to better develop these ideas and examine examples of this approach being applied in member countries, such as project EVAD in France, or elsewhere.

ToR b) Postponed.

ToR c) Postponed.

ToR d) Postponed.

ToR e) Postponed.

ToR f) Postponed.

ToR g) The WGEIM developed a risk assessment framework to better understand the current and future risks to wild fish populations due to cage culture of finfish in OSPAR countries (OSPAR request 2010/3). Specifically, risks evaluated included ecological interactions with wild fish due to escapees, the use of fish feed based on fish meal and fish oil on target fish stocks, and indirect ecosystem effects of fishing target fish stocks. Risk due to genetic interactions and disease transfer from cage sites were covered by the WGAGFM and the WGPDMO, respectively. The level of risk (consequence), and likelihood of consequences were determined and a global level of risk assigned to each activity as was a level of uncertainty – a relative indication of the quality and quantity of data available to support assigned levels of risk and likelihoods. The work focussed on salmonid aquaculture as this is the dominant culture type occurring in OSPAR countries. Although cod (*Gadus morhua*) farming is becoming more important regionally, the importance of this activity accounts for a small

fraction of total production of fish in cage culture in OSPAR countries (ca. 2%), which is dominated by farming of salmonids (ca. 97% of a all production) and there is relatively little information with respect to the ecological significance of this practice on wild fish populations.

Although codes of best practice have reduced the number of escapees in salmonid aquaculture in recent years, catastrophic escapes still occur and there is little information on the importance of chronic escapes, although some estimates suggest that this may be substantial, and for non-salmonid species. Consequences identified for escaped salmon typically varied between minor to moderate with low uncertainty and were considered to be rare or else likely. Overall, perceived risks were greatest with respect to the use of fish feeds in aquafeeds, followed by various types of competition between escaped and wild salmonids. Given the growth of the industry and notwithstanding the recent decreases in escape rates, it is expected that risks to wild fish stocks will increase as the industry expands.

It is suggested that the risk assessment framework developed could be used by other EGs to address genetic and disease issues. It is also suggested that EGs with more expertise on fishing effects (e.g., the WGECO) could expand the assessment on fishing for aquafeeds portion of the current assessment.

Information for the SSGHIE on potential and current contributions of the WGEIM and WGMASC to the Strategic Initiative on Coastal and Marine Spatial Planning (SICMSP) are included in ToR i.

Plans for the SSGHIE to promote cooperation between the WGEIM and WGMASC, which cover similar scientific issues, are included in ToR i.

WGEIM and WGMASC agreed to have joint meetings every 3 years. Chairs of both groups invite key members to the annual meetings to work on overlapping ToRs together. Chairs will exchange draft reports immediately after their respective meetings. The groups identified SSGHIE expert groups where there may be potential for collaboration (Chapter 5).

A discussion of WGMASC and WGEIM on the Second Draft of the Bivalve Aquaculture Dialogue Standards was carried out. The management framework takes a market-based approach with the associated costs largely borne by industry. This is a simplified ecosystem-based approach and, as such, excludes many ecosystems services that the cultured bivalves provide that may mitigate negative effects. Other emerging shellfish aquaculture issues were identified: - restoration of cultured shellfish populations, nutrient trading by culturing shellfish, use of shellfish compounds to cure disease, co-management in shellfish aquaculture (Chapter 6).

The next meeting was arranged for 2–6 May 2011 in Charlottetown, Canada.

1 Opening of the meeting

The ICES Working Group on Environmental Interactions of Mariculture (WGEIM), chaired by Chris McKindsey, Canada, held its meeting in Galway, Ireland, on 29 March – 2 April 2010 at the Marine Institute. It was attended by 6 members and one chair-invited guest (Annex 1). The meeting was held at the same location and during the same days as the ICES Working Group on Marine Shellfish Culture (WGMASC). The host Francis O'Beirn, member of both WGMASC and WGEIM, opened the joint WGEIM–WGMASC meeting at 9:00 am on Monday, 29 March and gave housekeeping information. John Evans, director of Marine Environment and Food Safety Services, officially welcomed the groups at the Marine Institute. The chairs welcomed the members to the meeting and thanked their respective institutions for allowing time and money to participate. It is becoming increasingly difficult for institutes to allocate resources for the ICES WGs. Four members from the US and Canada were not able to come because of lack of funds and thus several ToRs were not addressed. New members from Scotland (Matt Gubbins), Germany (Ulfert Focken), Norway (Karin Boxaspen) and a chair-invited guest from Ireland (Myriam Callier) were welcomed.

2 Adoption of the agenda

A primary objective of the meeting was to address concerns of mutual interest and expertise between the WGEIM and the WGMASC and the first day of the meeting was devoted to identification of overlap and subjects of mutual interest between WGMASC and WGEIM and ways to cooperate during the meeting. In addition, the roles of WGEIM and WGMASC within ICES were discussed. This is reported on in Chapter 8 (ToR g). Subjects of mutual interest and procedures to avoid duplication were discussed in plenary (Chapter 5).

Also, the Draft for Final Public Comment Period of the Bivalve Aquaculture Dialogue Standards coordinated by the World Wildlife Fund (WWF) was discussed in a plenary session at the beginning of the second day with both groups. Both the WGMASC and the WGEIM have worked on sustainability indices for bivalve aquaculture and have a view on the document. The outcome of this discussion and further discussions with the separate groups is presented in Chapter 6.

The agenda (Annex 2) was modified slightly and formally accepted on day 2 by the EG. A general discussion on plans for each WGEIM ToR was held and it was decided to concentrate on a reduced number of ToRs. Thus a select subset of ToRs was addressed over the following days after the EG was divided into working subgroups. Sub-group leads, chosen based on their previous involvement, reported daily in plenary and the group as a whole contributed to each ToR. A substantial part of the work was done after the close of the meeting and commented upon via correspondence through the sub-group leads.

3 ToR a) Evaluate the examples of sustainability indices proposed for mariculture activities and critically evaluate those SI's recommended by WGEIM and other fora

Leads: Thomas Landry, Myriam Callier, Francis O'Beirn

Progressing Sustainability in Mariculture

The issue of sustainability of mariculture operations has been addressed by WGEIM among other ICES experts groups) for a number of years. More recently WGEIM (2006, 2007, 2008) has attempted to identify suitable indices that could be used to assess the sustainability of aquaculture and how this activity interacts with others in the marine environment. Initially the group identified the criteria required to define a suitable indicator followed by reviews of various initiatives addressing the issue of sustainability. The criteria that define an appropriate sustainability indicator is that it must be:

1) scientifically credible,
2) reflective of conditions at the system level,
3) flexible and adoptive to a range of conditions and systems, and
4) easy to communicate to all stakeholders.

Previous reviews have typically taken the form of either evaluations of specific programs set up to identify and develop sustainability indicators (DEPOMOD, ECASA, EVAD) or various scientific publications focusing upon principles to ensure sustainability (i.e., Soto *et al*. 2008; NRC 2010; Tucker and Hargreaves 2008). It is generally accepted that the main goal of many programs, however, has been to determine an acceptable aquaculture production capacity for a defined area. To that end a typical outcome of reviews and programs is that they, for the most part, have led to the promotion of specific and localized "sustainability" or impact indicators. The difficulty, therefore, in determining the sustainability of aquaculture, specifically where it might fit in with the evaluation of the health of marine systems generally and how it might interact with other activities, remains.

While the specific question of sustainability has been addressed to some degree at the level of an individual activity (i.e. aquaculture operations) it is acknowledged that aquaculture activities should be managed while fully cognisant of other activities in a particular area. Consequently, the likely impacts of aquaculture will therefore have to be assessed individually, cumulatively (with other aquaculture operations) and in-combination with other activities, on the environment, ecosystem and function of a system. Applying this has proved somewhat problematic. The interactions and impacts of aquaculture have been well-documented; this information has provided the framework for assessment of impacts and the development of monitoring programs for aquaculture operations as well as identifying those levels of activity that might be deemed acceptable. The notion of "acceptability" is critical to fully determining the sustainability of activities in the marine environment. The term "acceptable", is governed primarily by social values, derived from a global vision for what a system should resemble. Therefore, the extent of activities in a system might be governed by global objectives (socially derived) for that system. Thus the social carrying capacity of a system should form the basis of a sustainability program to assess the sum of activities, including aquaculture, within a defined area. The principle goals of sustainability may be directed by a global vision of what is important but effected at a local or regional level. For example, the global vision of "no net loss of biodiversity" may be a global vision that could be implemented at the scale of an embayment.

This notion of a global overview of sustainability in marine systems is an underlying principle of Integrated Coastal Zone Management (ICZM). Towards this goal of ensuring estimation of total sustainability of activities in the marine environment, the WGEIM first reviewed/proposed the concept of Integrated Coastal Zone Management (ICZM) in 1995. In the interim, terms of reference of the group have been discussed and reviewed wherein the value managing marine resources utilizing an integrated management systems was discussed. The group continues to reiterate the importance of linking social, economic and environmental aspects into the management of marine systems and also emphasized the need to have broad sectoral cooperation and input into the development of these practices. Two dimensions highlight the goals of the group:

1) vertical integration of governance in the form of policies, management arrangements from national to local levels of government, including community-based approaches, and
2) horizontal integration of policies, management arrangements and development plans across national, district, or local levels of government as well as among different stakeholders with common interests in coastal areas and resources.

The group has emphasized the need to create a shift from management and regulation of activities in the marine environment in isolation, to a system where all activities can be considered in unison and that resource use is optimized such that the overall health and productivity of the coastal ecosystem is maintained. These goals are ambitious and their implementation presents a challenge. The group recommends that development of appropriate decision support systems (DSS) can be supported by consideration of the spatial and, perhaps, temporal requirements of mariculture in combination with the requirements of other activities. Such an analysis may also help identify opportunities for further development of aquaculture in coastal areas. Conflicts may potentially be resolved by stakeholder consultation and application of broader policy guidelines influenced by developmental or legislative drivers.

Initial descriptions identify the pressures that mariculture systems exert on natural systems. Benthic and pelagic effects are well documented in the literature (from both modeled and empirical studies). The risk posed by practices associated with aquaculture (both finfish and shellfish) have also been well documented and evaluated in the areas of disease transmission and introductions of exotic species to areas. The *in-depth* knowledge relating to these impacts and interactions have placed the pressures posed by mariculture to the forefront in terms of public awareness and criticism. Ironically the lack of information pertaining to other pressures may be a reason they have not been the focus of scrutiny or criticism (e.g. static gear fisheries, diffuse pollution).

A number of subsequent WGEIM reports (e.g. ICES 2002, 2007) have highlighted that a social science dimension should be brought to bear on the issue of CZM within ICES. Specifically, it was recommended in WGEIM 2002 that, to better understand the perception of threats felt by the different stakeholders competing for space and resources in coastal areas, emphasis should be given to research in the social sciences to help establish a consensus among users in coastal zones (e.g., within the framework of an ICZM initiative (e.g., Section 7, consensus-building)).

EVAD (EVAluation de la Durabilite des systèmes aquacoles: Cirad *et al*. 2008) addresses the issue of aquaculture sustainability from two different perspectives: the contribution that aquaculture systems make to the sustainability at regional levels and the sustainability factors for aquaculture farms themselves. The first component of this approach appears broadly to be an application of Integrated Coastal Zone Management based on the DPSIR (Driver Pressure State Impact and Response) model to achieve sustainability at the regional level. The ICES Working Group for Marine Shellfish Culture (ICES 2009) framework also recommended an ecosystem approach be taken to aquaculture management that is comprehensive and based on the best available scientific knowledge of the ecosystem and its dynamics. Actions are designed to mitigate the influences of aquaculture developments that are critical to the health of ecosystems, thereby achieving sustainable use of ecosystem goods and services and maintaining ecosystem integrity. The FAO has also produced guidelines (Soto *et al*., 2008) intended for the production of improved shellfish aquaculture certification schemes that comply with the main principles of the ecosystem approach. In these instances, the aim is to assess of the sustainability of all activities in an area where aquaculture is fully and fairly integrated rather than the sustainability of aquaculture in isolation. At that point, indicators can be developed, negotiated and used to evaluate the effects or impacts (positive and negative) of aquaculture and other activities (drivers) on the sustainable utilisation of resources in a region, based upon the global principals and effected using regional-territorial criteria. Sustainability would thus no longer be assessed by indicators of impacts, but mainly by criteria based on broader objectives and ecosystem standards that consider all activities within a system. The sustainability of all activities within a region would thereby be evaluated on the merit of criteria developed under an Integrated Coastal Zone Management (ICZM) approach. Assessment of sustainability at the activity level may lead to the establishment of thresholds that may be ineffective or even detrimental to the activity and may only contribute marginally to one or several criterion. In addition, smaller aquaculture operations would not be constrained by the responsibility of monitoring the sustainability of an area, because they are the newer addition to the coastal zone region, already affected by numerous players.

Recent efforts to develop sustainability standards, indicators and certifications are still, to a large extend, focused on the use of impact indicators and thresholds. The World Wildlife Fund's Bivalve Aquaculture Dialogue (BAD) is an example of this phenomenon. The aim of the BAD standards is to provide "a means for shellfish farmers to measurably prove the environmental and social sustainability of their farming operations", based on 7 principals. The basic principles underlying the development of these standards harbour ambitions towards the development of a 'total' or broad system-wide sustainability indicator. However, the focus on a single sector (shellfish aquaculture) and the reversion to the application of impact indicators with little or no attention paid to possible beneficial impacts of aquaculture activities presents a truncated picture of the influence of shellfish aquaculture in the environment (see Chapter 6). A decision should be taken, by managers in consultation with all stakeholders of the system, as to what the goals (global vision) for the system are. Consideration should be given to both the positive and negative aspects of any proposed development and whether the positive aspects outweigh the negative ones? All factors should be brought to bear on the decision making process. For example, will the mitigation of eutrophication effects afforded by the filtration of shellfish outweigh the increased bio-deposition beneath the culture structures?

In summary, we are still faced with a dilemma in terms of the development of sustainability indicators at the regional level. It would appear that the focus should be on the development of system-wide objectives with the establishment of appropriate metrics to measure those objectives. All activities should be considered when licensing activities in a system, i.e. both positive and negative aspects must be measured. In addition, the views of all stakeholders must also be considered. Notwithstanding the social aspect it must also be important to consider legislative constraints that might preclude the licensing of activities in a system, e.g., nature conservation goals (or sensitive habitat) that might be directly impacted by any one activity. In light of the preceding, a number of important questions remain:

1) where are we in terms of developing system-wide indicators of sustainability/health?
2) where are we in identifying those points or thresholds that are deemed acceptable in a systems – taking into account all of the activities and the views of all stakeholders as well as legislative drivers and constraints?
3) Where are we in terms of developing management systems that are used to make decisions in the marine environment? Will employing the principles of ICZM aid in the development of SI. Is it accepted that the focus on activities should be balanced and the good can be taken with the bad? To that end, it may be possible to define the sustainability of a farm (unit) in taking into account the positive and negative impact of a unit on the whole system, as well as the role of other activities in the same area?

References

ICES.2007. Report of the Working Group on Environmental Interactions of Mariculture (WGEIM), 16–20 April 2007, Kiel, Germany. ICES CM 2007/MCC:02, 60 p.

ICES. 2002. Report of the Working Group on Environmental Interactions of Mariculture (WGEIM), ICES Headquarters 8–12 April 2002. ICES CM 2002/F:04 105 p.

ICES 2009. Report of the Working Group for Marine Shellfish Culture. (WGMASC). 7–Bremerhaven, Germany, 9 April 2009 ICES CM 2009/MCC:02

National Research Council. 2010. Ecosystem concepts for sustainable bivalve mariculture. National Academy Press, Washington, DC.179pp

Soto, D., J. Aguilar-Manjarrez, J. Bermúdez, C. Brugère, D. Angel, C. Bailey, K. Black, P. Edwards, B. Costa-Pierce, T. C., S. Deudero, S. Freeman, J. Hambrey, N. Hishamunda, D. Knowler, W. Silvert, N. Marba, S. Mathe, R. Norambuena, F. Simard, P. Tett, M. Troell, and A. Wainberg. 2008. Applying an ecosystem-based approach to aquaculture: Principles, scales and some management measures. In Building an Ecosystem Approach to Aquaculture, Soto, D. and N. Hishamunda (eds.). Food and Agriculture Organization of the United Nations, Rome, Italy.

Soto, D.; Aguilar-Manjarrez, J.; Hishamunda, N. (eds). Building an ecosystem approach to aquaculture. FAO/Universitat de les Illes Balears Expert Workshop. 7–11 May 2007, Palma de Mallorca, Spain. *FAO Fisheries and Aquaculture Proceedings*. No. 14. Rome, FAO. 2008. 221p

Tucker, C.S. and J.A. Hargreaves. 2008. Environmental best management practices for aquaculture. Wiley-Blackwell. 592pp

4 ToR g) Effects of mariculture on populations of wild fish (OSPAR request 2010/3)

Leads: Chris McKindsey, Karin Boxaspen, Ulfert Focken, Matt Gubbins)

While there is general agreement on the range of potential forms of interaction between farmed and wild stocks, there is much less agreement on the current and future significance of these interactions for wild stocks. OSPAR ask ICES:

- To provide advice on the current state of knowledge on the interaction of finfish mariculture on the condition and wild fish populations (both salmonid and non-salmonid) both at a local and regional scale, including from parasites, escaped fish and the use of fish feed in mariculture. Advice is requested on how the interactions will change as a result of an expansion of mariculture activities.
- OSPAR suggest that this should be addressed through a risk analysis approach, making best use of both quantitative and qualitative methodologies, and that an important aspect of the outcome will be clear identification of the specific aspects of the risk analysis where additional research effort may best be targeted to reduce the uncertainty in the risk analysis.
- This work should be coordinated between WGEIM and WGAGFM through communication between the chairs and correspondence.

4.1 Introduction

Capture fisheries and aquaculture production

The world-wide production of fisheries products has been increasing steadily from the middle of the last century from a total production of about 20 million tonnes per year to about 160 million tonnes per year in 2008 (Figure 1, see Figure 2 for OSPAR countries). Of this total, the amount taken each year in the capture fisheries has remained stable since the end of the 1980s at about 90 million tonnes per year. The difference in total growth of production has been made up by great increases in aquaculture-related products, the production of which has increased at a rate of about 7% per year since the 1970s, accounting for 43% of the total fisheries production and 47% of the total production destined for human consumption in 2008 and passed 50% of the production for human consumption in 2009. As most fisheries fish stocks are currently being fished to or beyond capacity (Worm *et al.*, 2009) and the demand for seafood products is projected to increase due to human population and economic growth, this trend is likely continue and aquaculture production will become increasingly important around the world (Asche *et al.*, 2008).

Environmental concerns

This increased production has led to increased concerns about the impacts of the activity on the local environment and the ecosystem (e.g., Black, 2001) and there has been much work towards understanding the role of aquaculture in the environment (e.g., Davenport *et al.*, 2003; Holmer *et al.*, 2008) and developing a more “sustainable” industry (e.g., Costa-Pierce, 2002; Stickney and McVey, 2002). With respect to finfish farming, there are concerns about various issues: organic loading (Black *et al.*, 2008; Hargrave, 2005), escapes (competition and predation), genetic issues (from escapes or releases of farmed organisms or their propagules), and diseases (foci for disease and transmission to wild stocks from culture sites or released stock) (Ford and Myers, 2008; Naylor *et al.*, 2005), and impacts on forage fishes harvested to produce fish meal and oil used in feed for farmed fish (Naylor and Burke, 2005; Naylor *et al.*, 2000; Tacon and Metian, 2009a).

Fish species farmed in OSPAR countries

The total production of fish species in aquaculture by OSPAR countries in 2008 was 1.26 million tonnes, of which 1.07 million tonnes was from marine and brackish waters (hereafter referred to together as "marine") in the Atlantic Northeast (FAO major fishing area 27, see Table 4.1.1); the remainder of the total production was grown in other areas – mostly freshwater where 115 thousand tonnes of rainbow trout accounts for the greatest proportion of fish produced. Of the fish produced in the marine environment, Atlantic salmon were by far the most important species, accounting for 86% of the total production in 2008. Rainbow trout were the next most important species, accounting for a further 10% of the total production, and Atlantic cod a further 2%. Norway was by far the most important producer of the top 3 species, accounting for 80.1, 69.4, and 84.4% of the production of each of these species, respectively. Other important producers of Atlantic salmon were the UK (Scotland, 14.0%) and Denmark (Faroe Islands, 4.2%). Other important producers of rainbow trout were Denmark (Denmark: 9.4%; Faroe Islands: 6.9%) and Finland (9.9%). The UK and Iceland accounted for 8.5 and 7.0% of the remaining production of Atlantic cod, respectively.

Table 4.1.1. Production (1000s of tonnes) of the 5 most important fish species (by biomass) and total production of fishes in marine/brackish aquaculture in the Atlantic Northeast by OSPAR countries since 1999. Data from FAO (2010).

Species	Year									
	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Gilthead seabream	1.4	1.8	1.8	3.5	3.0	3.2	4.0	3.7	4.3	3.4
Turbot	4.1	4.8	4.9	5.3	5.4	6.0	6.8	7.7	8.2	9.5
Atlantic cod	0.2	0.2	1.0	1.5	2.6	3.8	8.1	13.2	13.7	21.4
Rainbow trout	75.9	74.5	97.4	113.6	99.8	91.6	87.1	90.6	106.4	108.6
Atlantic salmon	613.3	623.0	647.0	678.4	728.3	784.3	756.7	792.7	908.9	921.6
Total	697.9	707.3	755.0	805.5	843.2	893.5	869.9	916.0	1050.0	1072.4

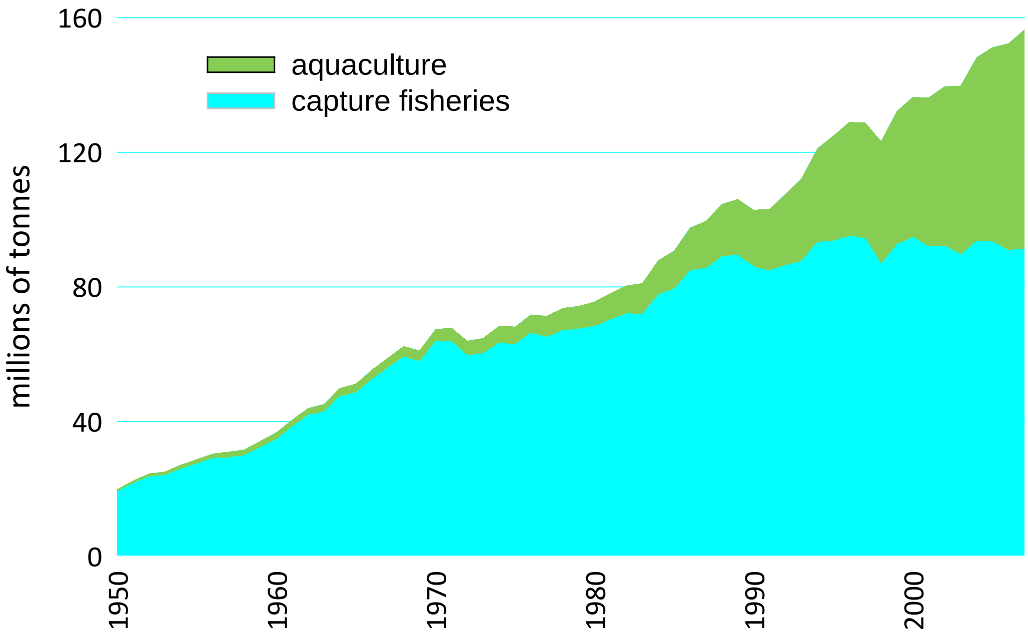


Figure 4.1.1. Global fisheries and aquaculture production (all taxa combined, data from FAO, 2010), 1950–2008. Note that the proportion of aquaculture production of the total of fisheries and aquaculture production destined for human consumption accounted 47% in 2008 and surpassed 50% in 2009. Since the late 1980s, about 29 Mt of the total capture fisheries production is destined for non-food uses, predominantly for the production of fish meal and fish protein.

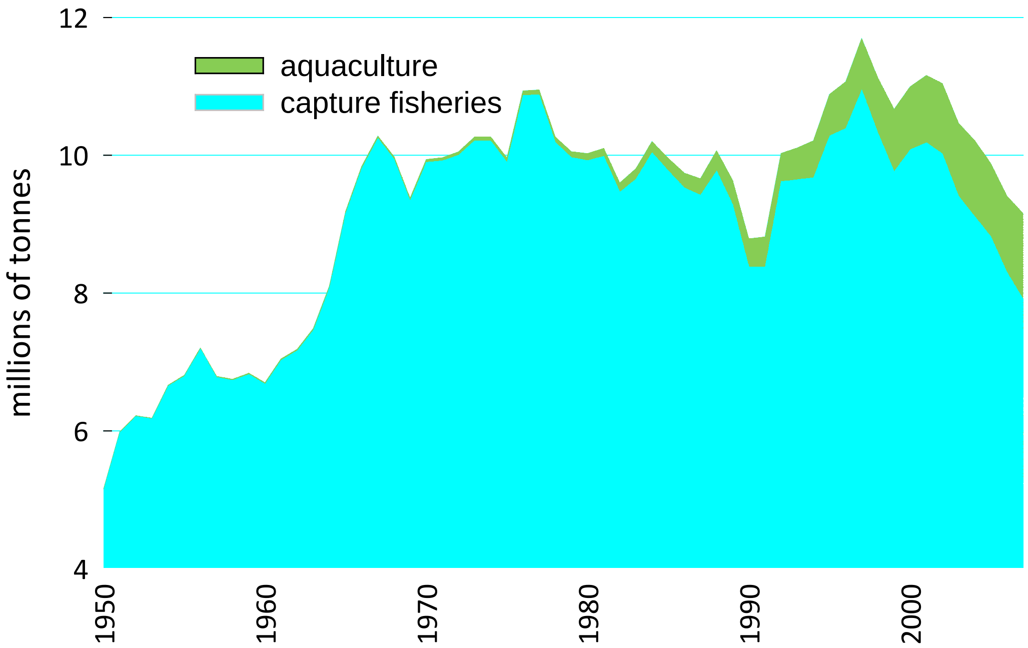


Figure 4.1.2. Fisheries and aquaculture production of fishes by OSPAR countries (data from FAO, 2010), 1950–2008. Landings from capture fisheries are currently decreasing whereas those from aquaculture are increasing.

Objectives

As a consequence of this increasingly important economic sector and ecological reality, OSPAR has requested that a risk assessment be undertaken to evaluate the potential risks to wild fish associated with this industry (see request in Appendix). The current work is a quantitative risk assessment for marine fish farming in OSPAR countries covering issues relating to the risks associated with the escape of farmed fishes or their reproductive products and their interactions with wild fishes with respect to predator-prey and competitive relations and disease transmission and their competition for food, space, and reproduction with wild conspecifics. Impacts on fish stocks used in the production of fish meal and oil used to produce aquafeeds for the farmed fishes are also covered. Impacts due to genetic interactions and disease transmission from farm sites are not covered in the current review as they are being covered by the WGAGFM and WGPDMO, respectively. Impacts due to organic loading and other issues are not being considered in the current process. Given the vast research done on Atlantic salmon (*Salmo salar*) relative to other fish species, this work is largely founded on work done on this species. Reference to work done on other species is given when possible.

Table 4.1.2. Qualitative measures of consequences of various ecological interactions between escaped fishes from aquaculture on populations/communities of wild fishes of the same or other species.

Level	Descriptor	Detailed consequences
1	Insignificant	No impact, or changes in fish populations/assemblages not readily detectable or of short duration and small spatial scale
2	Minor	Limited impacts, changes in fish populations/assemblages in terms of abundances and diversity are detectable but are of short duration (seasonal to year) and small spatial scale (immediate vicinity of farm site)
3	Moderate	Considerable impacts, changes in fish populations/assemblages in terms of abundances and diversity are moderate and are of moderate (year scale) duration and spatial (bay scale)
4	Major	Great impacts, changes in fish populations/assemblages in terms of abundances and diversity are marked and are of long (multi-year scale or permanent) duration and spatial (coastal scale or greater)

Table 4.1.3. Quantitative measures of consequences of the use of fish feed in aquaculture: impact on target fish stocks.

Level	Descriptor	Detailed consequences
1	Insignificant	No targeted fisheries products are used in feed Only fisheries by-products used
2	Minor	Targeted species fished within sustainable limits
3	Moderate	Targeted species is fished within sustainable limits but geographic range reduced
4	Major	Targeted species is fished to beyond sustainable limits

4.2 Methods

Risk assessment

Risk assessment is a process whereby risks are quantified, to the extent possible, using available quantitative or qualitative data, to inform a risk analysis. The evaluation includes the identification of risks, determining the importance or magnitude of each risk (the consequence), the likelihood of each occurring, and assigning a level of uncertainty for each consequence and likelihood. In the current work, we use a standardized risk assessment framework as outlined by Crawford (2003) with the addition of a measure of uncertainty for each parameter evaluated. The inclusion of this latter information is standard in many risk assessments and adds important information for managers to consider when conducting the full risk analysis. A risk analysis is part of the larger risk management framework and includes social and economic aspects. Both of these processes are beyond the scope of the current work, but are important in the greater risk management process.

Because of the complex nature of ecosystems, a classification scheme for the ecological consequences of an activity is difficult. As classification of levels of consequences is dependent on an individual's understanding and perception of detrimental ecological effects, Crawford (2003) suggests that predefining a scale of impacts may facilitate the task. In the current process, a number of qualitative measures of consequences were developed to consider the impact of fish farming on the ecological interactions between escaped farmed fish and wild fish of the same or different species (Table 4.1.2). Qualitative measures of consequences of commercial fishing for fishes for fish products used in the production of aquafeeds for fish culture were also developed for consequences to target fish stocks (Table 4.1.3) and for the ecosystem in which such fishing occurs (Table 4.2.1). Mechanisms by which these consequences result are given in Appendix II. The other tangent of a risk assessment is the likelihood of a given consequence occurring. We have divided this into 5 unequal classes, reflecting the WGEIM's collective logic of the importance of different likelihoods. These are outlined in Table 4.2.2.

An important step in the determination of overall risk is the identification of the level of certainty associated with a particular risk, i.e., the probability of a given consequence of occurring and of its magnitude. In general, great uncertainty increases the risk of a consequence as it is unsure whether such a consequence is likely or not. One way of categorizing uncertainty is by having much information on a given consequence and being able to classify the range of magnitude of consequences observed. This is rarely the case with ecological data. A more logical approach, in this case, is to use a weight of evidence approach. In this case, uncertainty is least when there is a substantial weight of peer-reviewed information (e.g., scientific articles, studies, etc.) on a given subject and greatest when there is little or no information on a given subject, often simply the opinion of an expert on a related consequence. We thus ascribe the "uncertainty" of each magnitude and likelihood of each consequence as outlined in Table 4.2.3.

Table 4.2.1. Quantitative measures of consequences of the use of fish products to produce aquafeeds: Ecosystem-level effects of fishing target fish stocks.

Level	Descriptor	Detailed consequences
1	Insignificant	No (physical) impact of fishing activity on seabed, no reduction in stock abundance, fish size and range as a result of fishing activity, no bycatch from targeted fishing activity, or impacts on habitat, biodiversity, ecosystem functioning are within natural variation
2	Minor	Short-term (physical) impact of fishing activity on seabed, or reduction in stock abundance, fish size, or range as a result of targeted fishing activity, limited by-catch from targeted fishing activity, or impacts on habitat, biodiversity, ecosystem functioning
3	Moderate	Long-term (physical) impact of fishing activity on seabed, reduction in stock abundance, fish size and range as a result of targeted fishing activity, substantial by-catch from targeted fishing activity, or notable impacts on habitat, biodiversity, ecosystem functioning.
4	Major	Long-term destruction of seabed due to physical impact of fishing activity resulting in loss of critical habitat and permanent reduction in stock abundance with notable consequences for other trophic levels (biodiversity, ecosystem functioning)

Table 4.2.2. Qualitative measures of likelihood with respect to interactions from cage finfish culture.

Level	Descriptor	Description	Probability of event occurring
A	Rare	Event may only occur in exceptional circumstances	<5%
B	Unlikely	Event could occur but is not expected	5–15%
C	Possible	Event might occur at some time	16–50%
D	Likely	Event will probably occur in most instances	51–95%
E	Almost certain	Event is expected to occur in most instances	>95%

Table 4.2.3. Levels of uncertainty with respect to consequences and likelihood of various ecological interactions between escaped fishes from aquaculture on populations/communities of wild fishes of the same or other species.

Uncertainty level	Description
Very high (VH)	Little or no information; expert opinion based on general principles; "best guess"
High (H)	Limited information; third party observational information or circumstantial evidence
Moderate (M)	Moderate level of information; first hand, unsystematic observations; opinions based on related systems
Low (L)	Considerable scientific information; non peer-reviewed information
Very low (VL)	Extensive peer-reviewed body of scientific information

Together, the magnitude and likelihood of consequences occurring give the level of risk associated with a given activity. Thus, a given minor consequence with a very rare probability of occurring will have a lower risk than a moderate risk with a very high probability of occurring. We combined these two qualitative scores within a risk matrix that ascribes overall risk with a given activity (Table 4.2.4). It must be understood that a given risk rating for a specific consequence cannot be compared with a consequence measured using a different metric. Thus, in the current analysis, comparisons may be made as to the relative importance of (for example) consequences classified within Table 2 but not between 2 tables of consequences (e.g., comparing risk of modifying a population of fish versus modifying the functioning of an entire ecosystem).

Data to feed risk assessments are often contained within separate synopses. In the current process, this is not the case as this work is to stand alone. To this end, we present a brief review of the pertinent literature on the subjects of interest which will be used as a basis for ascribing consequences and likelihoods. The sheer weight of evidence for some subjects will make ascribing levels of consequences and likelihood fairly simple. For example, much is known about the ecology of escaped salmon. In contrast, other subjects are much less-well studied and understood, making consequences and likelihoods difficult to ascribe and thus increasing uncertainty. A good example of this is the ecological impacts of propagules from fish spawning in net pens, for which little information is available.

Table 4.2.4. Qualitative risk analysis matrix (level of risk). Risk is a function of the likelihood of an even occurring and its consequence. Overall, risk is classified as negligible (green), low (yellow), moderate (orange), or high (red).

Likelihood of event occurring	Consequence			
	1. Insignificant	2. Minor	3. Moderate	4. Major
A (Rare)	N	L	L	M
B (Unlikely)	N	L	M	M
C (Moderate)	N	L	M	H
D (Likely)	N	M	M	H
E (Almost certain)	N	M	H	H

N = negligible; L = low, M = moderate; H = high

Given this, the chapter examining the impacts of escaped fish on wild fish populations is divided into 2 sections: one addressing Atlantic salmon (and other related salmonids, as available) and the other addressing Atlantic cod (and other fishes that may spawn within net cages and for which little or no information is available). The impacts of industrial fishing for fish to produce fish products used in aquafeeds for farmed fish are similarly divided into 2 sections, the first examining the impacts on the stocks that are fished, and the latter examining the greater impacts of this activity on the ecosystem.

4.3 Overview of issues relating to fish cage culture in OSPAR countries and consequences and likelihood (= level of risk) associated with each activity

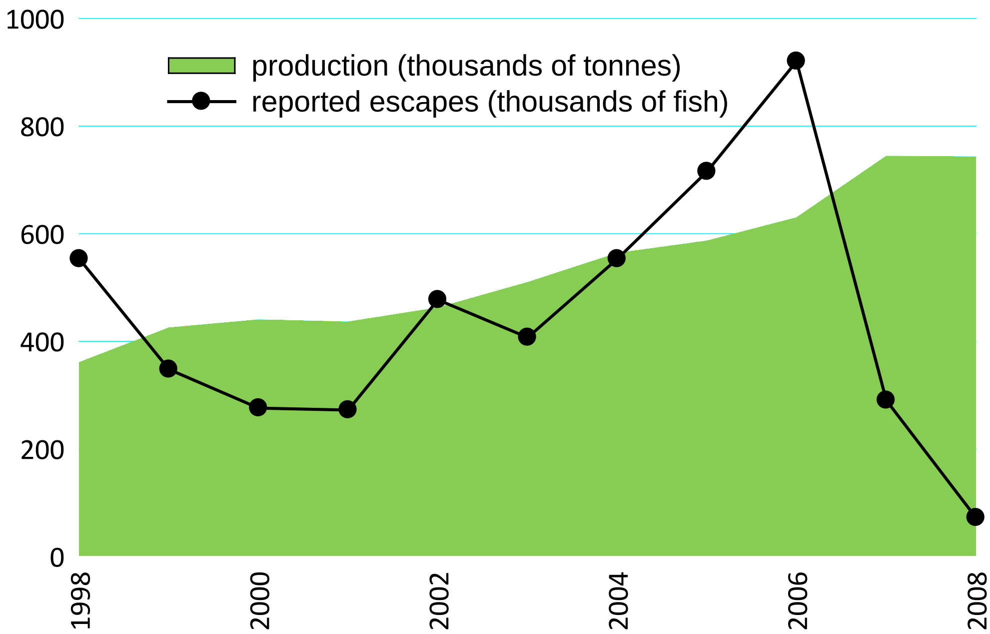
4.3.1 Impacts due to escapes

4.3.1.1 Magnitude of escapes

Fish may escape at any stage of development, from eggs and gametes through juvenile to adult stages (Cross *et al.*, 2008). Of course, the chances for survival are very dependent on the stage that escapes, on season, location, etc., as are the potential impacts. Mortality is usually greatest immediately following escapement as cultured animals must adapt to capturing wild food and escaping predators.

Escapes of fishes from net pens may be considered as either chronic or acute (Bridger and Garber, 2002). Chronic escapes are the "leakage" of fish from culture sites resulting from improper farm practices (e.g., dropping fish during transfers), small holes in containment netting, escapes by sub-size individuals through netting, etc. In contrast, acute losses are massive losses due to holes torn by predators or damage due to storm events that may result in near or total loss of fish in net pens. In general, the number of fishes escaping from fish farms is poorly known. Estimates range from less than 1% to greater than 6% of the fish in sea cages, depending on species, size, etc. (Leggatt *et al.*, in press; Moe *et al.*, 2007; Thorstad *et al.*, 2008). Although known losses must be reported in most jurisdictions, the number of losses is likely under-reported in official statistics. For example, although reported losses by the Norwegian salmonid culture industry averaged just under half a million fish annually over the period 1998–2008 (see Figure 4.3.1.1.1), Sægrov & Urdal (2006, reported in Thorstad *et al.*, 2008) calculated that only 12–29% of the actual number of escaped salmon is reported in Norway. Skilbrei *et al.* (2006) suggest that the majority of aquaculture escapees they caught in a study to evaluate the provenance of salmon in Norway appeared to result from small, unreported escape events. Escape rates are also likely to be size- or stage-specific as well as species-specific. For example, cod (*Gadus morhua*) are presumed to have greater potential to escape than do salmon because of the propensity of the former to bite on and through netting and its willingness to enter openings (Moe *et al.*, 2007).

Figure 4.3.1.1.1. Annual production and reported escapes by the Norwegian Atlantic salmon aquaculture industry (data from FAO Fisheries and Aquaculture Department, 2010; and the Norwegian Fisheries Directorate, 2009, respectively).



Many of these fishes survive and become ecologically important in the functioning of the surrounding ecosystem. For example, Fiske *et al.* (2001) suggest that farmed salmon may outnumber wild salmon in a number of Norwegian rivers and averaged between 26 and 40% of the sea fishery for salmon in 2 areas between 1993 and 1999 because of the relatively large number of escapes. Despite the relatively (compared to Norway) small size of the Atlantic salmon culture industry in eastern Canada, given the reduced abundance of natural stocks in eastern north American Rivers (e.g., Amiro, 2003), escaped farmed individuals may also be more abundant than wild salmon in rivers in this area (Thorstad *et al*., 2008). They may also be present in areas where the species is not normally found, such as western North America and Chile (Morton and Volpe, 2002; Soto *et al*., 2006). In general, the abundance of escaped fishes in an area is a function of the abundance of farm sites or total number of fish being farmed in an area (Fiske *et al*., 2006). Many reviews discuss the importance (i.e., abundance) of escapees in natural systems in further detail (e.g., Bridger and Garber, 2002; Thorstad *et al*., 2008).

A number of fish species grown in cage culture in OSPAR countries may also contribute individuals to the natural environment via the release of gametes from individuals spawning within culture facilities. This includes Atlantic cod and sea bass. In some instances, the contribution of individuals of the former species via this pathway to wild stocks may also be substantial (e.g., Jørstad *et al*., 2008).

Given that the number of different farmed fish species may greatly outnumber the wild populations at the local level, even relatively small escapes may have important effects on local or wider-scale fish populations (Youngson *et al*., 2001). It is also clear that the number of farmed fish escaping may be large compared to the natural wild conspecifics.

4.3.1.2 Survival, dispersal, and migration of escaped fish

In order to have an impact on the surrounding ecosystem, fish escaping from culture sites must first survive. Surviving fish may then disperse from culture areas and perhaps undergo migrations. Each of these processes is quite variable and a function of the stage of fish that is released/escapes and the time of year/development at which this occurs. Thorough reviews of these processes for Atlantic salmon are provided by Weir and Fleming (2006), Thorstad *et al*. (2008), and the ICES WGNAS (2010); only a brief summary is provided here.

In general, farmed Atlantic salmon in the initial freshwater phase of their life cycle have reduced survival relative to wild conspecifics, as shown by Einum and Fleming (2001) in a meta-analysis of the existing data. This is considered to be a function of farmed fish being less well adapted to the receiving environment in terms of both genetic fitness and also due to their having been reared under hatchery conditions.

In general, Atlantic salmon smolts released into rivers migrate quickly downstream to the sea (Jonsson and Jonsson, 2006). Smolts from hatcheries that escape from marine sites will return to release areas and migrate up local rivers to spawn (Eriksson and Eriksson, 1991; Jonsson, 1997). Post-smolts released in the winter show poor survival and homing ability (Hansen and Jonsson, 1991). The former may be due to harsher winter conditions (less food, etc.) when natural populations have migrated away to areas with more clement conditions (Weir and Fleming, 2006). One study in a Norway (Jonsson *et al*., 1993) found that released post-smolts migrated away from release sites with the predominant current at a rate of ca. 1.6 km day^{-1} but at a rate of ca. 7.5 km day $^{-1}$ when moving along the open coast. Similarly, Skilbrei *et al*. (1998, cited in Thorstad *et al*., 2008) found that salmon released in an open coastal area with strong currents dispersed more widely than did fish released in areas without strong coastal currents. Salmon released in the autumn prior to attaining sexual maturity have poor survival whereas those released later in the winter had greater survival (Hansen *et al*., 1987). Adult farmed salmon seem to move away from farm sites quite quickly. Whoriskey *et al*. (2006) followed sonically tagged salmon released at two times in the year (January and April/May) from a cage site in Maine, NE USA. In both cases, fish typically moved away from cage sites within a few hours and, following the dominant currents, out into the more open Bay of Fundy. This same study also found that mortality of these fish was high and none of the experimental fish were observed to return and spawn in neighbouring rivers. In general, the "attractiveness" of a river for escaped farm salmon is scale-dependent with larger rivers attracting more escaped fish, even though they may be distant from release sites (Thorstad *et al*., 2008).

Survivorship of escaped adult salmon varies among locations and release dates. Hansen and Jacobsen (2003) found that recapture rates of tagged farm fish released in the winter were greater for those than those released in autumn. A second study done at 2 salmon farms in Norway (Hansen, 2006) found that escaped farmed fish recapture rates increased with the season with fish released in November being recaptured at a rate of only 0.2% whereas those released in March/April were recaptured at a rate of about 5%. In all cases, survival of farmed salmon is less than that of similar-aged wild conspecifics (Jonsson and Jonsson, 2006; Kostow, 2004; Thorstad *et al*., 2008; Weir and Fleming, 2006).

In general, farmed salmon escaping from sites in the NE and NW Atlantic and the Pacific may disperse over large spatial scale, at times being recovered thousands of km from release sites. (1995). Bridger *et al*. (2001) found that "escaped" triploid rainbow trout (*Oncorhynchus mykiss*) in Newfoundland, eastern Canada, tended to stay in the general farm area but eventually did disperse, more rapidly so in the winter than in the summer.

Migration into rivers by escaped farmed salmon lacking experience with their home river is often delayed relative to wild conspecifics (Jonsson *et al*., 1990; Jonsson *et al*., 1994) and may occur after wild salmon (Lund *et al*., 1991). If salmon are close to maturity when they escape, a large proportion of them may migrate successfully into local riverine systems over a short period of time. For example, Heggberget *et al*. (1993) found that 51% of "escaped" farm salmon migrated into a local (2 km distant) river within about 4 days of being released. Although, Økland *et al*. (1995) found that farmed Atlantic salmon may stay in rivers for less time than do wild conspecifics, this is not always the case and other studies have found that the two groups do not differ in river residence times for spawning (Thorstad *et al*., 1998). This latter study also indicated that farmed salmon may also undertake more within river movements during the spawning season than do wild salmon. A number of studies have also shown that farmed salmon may be distributed more randomly than are wild fish (Heggberget *et al*., 1993; Power and McCleave, 1980) or occupy areas upstream (Thorstad *et al*., 1998) or downstream (Power and McCleave, 1980) of wild conspecifics. Fleming *et al*. suggest that this may be due to farmed salmon lacking natural river imprinting or else being competitively inferior.

Taken together, it seems that the older a fish is when it escapes the more likely it will be able to survive and migrate to freshwater to interact directly with wild individuals. That being said, the older a fish is when it escapes, the less of a preference it will display for a certain river or river system, appearing to have lost their ability to navigate back to their "home" river (Jonsson and Jonsson, 2006). It is also clear that the proportion of salmon that escape from fish farms and survive is only a fraction of that of wild conspecifics although the absolute numbers of escaped fish may be greater if wild stocks are depleted and/or escapes are massive.

4.3.1.3 Overview of impacts due to escapes

4.3.1.3a. Issues not covered by the WGEIM

The best studied of all potential impacts due to aquaculture escapes is that of genetic effects operating at a variety of levels. Indeed, a number of reviews and risk assessments have been done on this subject, especially as they relate to Atlantic salmon (e.g., Cross *et al*., 2008; Naylor *et al*., 2005). In short, escaped individuals or genetic material (i.e., eggs and/or sperm) from farm sites may mix with wild stock and decrease the overall fitness of the different populations. This has been shown from both theoretical and empirical studies. These issues are covered further by the WGAGFM. Another issue of importance with respect to fish farm sites is the potential transfer of diseases from fish cage sites to fishes in the surrounding environment (Costello, 2009). These issues are covered further by the WGPDMO.

4.3.1.3b. Physiological and physical differences in farmed relative to wild fish

All life stages of farmed fish may differ from those counterparts in the wild. This is due to genetic selection for sought traits (e.g., fast growth, slow maturation, etc.), manipulations (e.g., triploid individuals) or else because the farm environment exerts specific developmental forces that may force different phenotypes (Jonsson and Jonsson, 2006). For example, the protected environment in which farmed fish are raised allows them to invest more of their consumed energy into protein growth and fat deposition, resulting in a number of morphological changes (Thorpe, 2004). These include smaller heads, rayed fins, and caudal peduncles in Atlantic salmon parr (Cramon-Taubadel *et al*., 2005; Fleming *et al*., 1994), and altered expression of secondary sexual characteristics in coho salmon (Hard *et al*., 2000). A number of other fish species, including Atlantic cod, also show precocious maturation under aquaculture conditions (Kjesbu and Witthames, 2007). Such changes likely influence their survival ability if escaped as well as their potential impact through interactions with wild fishes and the ecosystem.

4.3.1.3c. Impacts on other fish species due to escapes

We have identified 3 potentially important consequences of escaping fish on other fish species: 1) Predation on wild fish stocks of other species, 2) Competition with wild fish stocks (food/space), and 3) Disease transfer from escaped fish (see Table 8). Unfortunately, very little information is available or was identified in the current review with respect to the impacts of escaping farmed fish on other fish populations. The limited information that is available on the consequences of escapees that the WGEIM are covering (i.e., not genetic issues due to escapees or disease transfer from net pen facilities) are almost entirely focused on salmon escapees and their interactions on and with conspecifics. There is a near-complete lack of information on environmental interactions of escaped non-salmonid fishes from cage culture and wild fish populations. With respect to predation on wild fish stocks of other species, salmon become progressively more piscivorous as they grow and thus will impact some fraction of wild fish populations directly and indirectly through predation and competition for resources. With respect to competition with wild fish stocks (food/space), salmon are generalists in feeding habits and it is generally assumed that the ocean habitat is not limiting for salmon (see below) and thus not likely for their competitors either. Given this, we consider that the risk of escaped salmon to wild fish stocks of other species are typically insignificant with respect to predation and competition and that any effects that may occur are minor, restrained to the areas immediately surrounding farms, and rare – only occurring following massive escapes and only locally. That being said, the uncertainty associated with this is very high as the present review found no discussion on the importance of these effects on wild fish populations (see Table 8). With respect to disease transfer from escaped salmon to wild fish, although this idea is mentioned in several review papers, the current work found no work that has evaluated this explicitly and thus we consider the consequence of this to be minor although rare. Again, given that this subject has not been covered explicitly in the literature, the uncertainty of this is very high (see Table 8).

Effects of escaped salmonids on other salmonid species are covered below in the section on effects on the same species as the literature is often common for the same and differing salmonid species.

4.3.1.3d. Impacts on same species due to escapes

Given the more intense interactions between conspecifics or closely related species (e.g., similar salmon species), there is a greater potential for more and more important interactions between farmed and wild conspecifics and related species than between farmed fish and other fish species. These include: 1) Competition for food, 2) Competition for space, 3) Competition for reproduction, and 4) Disease transfer from escaped fish (see Table 8), and 5) genetic interactions. Genetic interactions between escaped and wild salmonids are very well studied and covered by other groups (i.e., WGAGFM). Below, we outline interactions between escaped farmed and wild fishes of the same species with an emphasis on the former four interactions. Potential consequences due to these are discussed in turn and classified as outlined in Table 2 and assigned a likelihood as outlined in Table 4. The certainty associated with each classification is also recorded as outlined in Table 6 and an overall level of risk assigned for each interaction as outlined in Table 7. Results of this exercise are summarized in Table 8. Given that the salmon considered in the present document are anadromous, there are important differences in the potential impacts of escapes at different life stages. As such, the consequences, likelihoods and risks due to escapes were divided into escapes during the first freshwater phase, the marine phase, and the second freshwater phase, where appropriate.

Salmon are typically at the greatest density in the freshwater portions of their lifecycle. Thus there is a greater potential for fry, parr, and smolts to compete than for the returning adults. Overlap in habitat use and diet suggests that farm and wild salmon compete for territories and food (Thorstad *et al*., 2008). With respect to feeding, Atlantic salmon are mostly opportunistic feeders on pelagic prey (e.g., Jonsson and Jonsson, 2006). Parr and smolts of farmed/hatchery origin have been show to outcompete feral salmon in head to head matches for food competition under simulated hatchery conditions but the results were the opposite under simulated natural conditions (Einum and Fleming, 1997; Fleming and Einum, 1997) and a number of studies have shown that this may be due to a greater aggressiveness in farmed fish (Jonsson and Jonsson, 2006). McGinnity *et al*. (2003) have also shown that faster-growing hatchery-derived salmon may displace smaller wild salmon downstream. In contrast, Fleming *et al*. (2000) found that farmed salmon were distributed further upstream of wild salmon than would have been expected based on the distribution of nests by wild and farmed females. In sum, effects of escaped juveniles in rivers with respect to competition for food and space are both expected to be minor with a “likely” likelihood and there is very low uncertainty about this given the multiple papers addressing the subject. This yields a risk ranking of moderate with very low uncertainty for the impact of escaped salmonids on wild conspecifics in the first freshwater phase with respect to competition for food and space (Table 8).

Once in the sea, a number of studies (e.g., Lacroix and Knox, 2005) have shown that prey species change along migration routes for Atlantic salmon. Other studies have shown that wild and escaped Atlantic salmon feed on the same prey types. For example, Jacobsen and Hansen (2001) showed that escaped and wild Atlantic salmon fed on similar food types in the Norwegian Sea, north of the Faroe Islands, with younger fish feeding mostly on crustaceans but becoming more piscivorous as they age. This same study showed that diets of both groups shifted by season such that crustaceans *Themisto* spp., euphausiids and mesopelagic shrimps were important in the fall but a variety of fishes became of equal importance later in the winter.

Although escaping farmed salmon logically compete with wild salmon for food in the wild (Naylor *et al*., 2005; Thorstad *et al*., 2008), ocean mortality of salmon seems to be density independent, suggesting that the carrying capacity of the ocean habitat has not been reached (Jonsson and Jonsson, 2004). Salmon may be cannibalistic in aquaculture situations and this may account for unaccounted for fish loss in some farm situations (Klemetsen *et al*., 2003). However, this review found no evidence of cannibalism in wild salmon or between farmed and wild salmon and, if it occurs, it is likely minimal. Consequences due to escaped fish on food resources may also be transitory – immediately following escapes – as Jonsson and Jonsson (2006) conclude from studies on other salmon species in western North America that competition for food between wild and escaped salmon may occur locally where there are large densities of escaped fish. Although this review also found no evidence that escaped salmonids impact wild conspecifics immediately after escapement but this could conceivably occur following massive escapes. Given this, we rate the consequence of escaped salmonids on conspecifics in the areas immediately surrounding farms following massive escape incidents as minor with rare likelihood for an overall risk score of low. Given the lack of published information on this, uncertainty is very high. We rate the consequence of escaped salmonids on conspecifics in the marine phase (post-dispersal from cage sites following escapes) as insignificant with respect to competition for food and space and with rare likelihood, providing a negligible risk rating for escaped salmon once they are in the oceanic phase of their lifecycle. Given that a fair number of studies have addressed this issue we consider the uncertainty associated with this to be very low for consequences, likelihood and thus overall risk.

Once salmon have migrated back to streams and rivers to spawn, the majority of studies have shown that farmed salmon will, all else being equal, typically win competitions with wild fishes for food. Again, this may be because farmed salmon may be more aggressive. However, prior experience with a site by wild fish will shift the balance such that they will win competitions more often than do escaped salmon. Thus, we assign a consequence of this of as minor with a likelihood rating of "likely" and very low uncertainty, yielding an overall risk of moderate with very low uncertainty.

Escaped farmed fish may also compete for mates in natural systems. However, as outlined above, escaped fish may not necessarily overlap with wild fish given that they may occupy different reaches in rivers or spawn at different times of the year. Weir *et al*. (2004) showed that male farmed Atlantic salmon were less able to form dominance hierarchies than were wild salmon. In contrast, farmed salmon courted and spawned with females in greater numbers but frequently failed to release sperm when females released eggs *et al*. (Weir *et al*., 2004). Taken together, this suggests that farmed males will have lower spawning success than do wild males. A review of spawning success of female Atlantic salmon by Thorstad *et al*. (2008) showed that the number of spawning redds by farmed salmon is often proportional to their relative abundance in rivers suggesting that they are equally successful at spawning as are wild females. However, egg numbers may be reduced. Overall, cultured salmon are competitively inferior to wild salmon and are injured more often than wild ones. That being said, given their greater abundance in some systems, their presence may have a considerable impact on local wild populations (Hindar *et al*., 2006). This may be particularly true if late-spawning farm escapees destroy redds of wild salmon. Given this potential overlap and competition for breeding sites and mates, we assign a consequence of this of as moderate with a likelihood rating of "likely" and very low uncertainty, yielding an overall risk of moderate with very low uncertainty for the risks of escaped salmonids to competition for space and reproduction in the freshwater reproductive stage of the fish's lifecycle.

Disease transfer from escaped fish to wild fish of the same species is not well studied and this review found no comprehensive work addressing the subject. We thus assign the consequence of this as minor with rare likelihood but there is very high uncertainty about this as little information on this is available, making for an overall risk score of low.

4.3.2 Impacts due to escapes of non-salmonid species

Very little information is available with respect to the consequences, likelihood, or risk due to escapes of non salmonid species from cage culture sites. Of greatest concern is Atlantic cod, which is being increasingly farmed, but it also includes other species, such as sea bream. In these species, both adults and propagules from adults breeding in fish cages may escape the confines of farm structures and interact with the fish in the surrounding environment. As expected, escaped farmed cod are predator naïve (Nødtvedt *et al*., 1999) and survival of released farmed cod increases with size at release (Kristiansen *et al*., 2000). Atlantic cod are piscivorous and thus any escaping individuals have some potential to impact wild fish populations. Escaped cod are likely to compete with wild cod for resources and, although they are initially less efficient at capturing wild food (Steingrund and Fernø, 1997), because of large liver energy reserves in escaped farmed cod (Grant *et al*., 1998; Kristiansen *et al*., 2000) and the availability of alternative food items (Nordeide and Salvanes, 1991b), they are believed to be able to survive the critical period between escape and adapting to a "wild" mode of existence and overcome an initial foraging disadvantage (Nordeide and Salvanes, 1991a; Salvanes and Braithwaite, 2006). However, given that this species has been greatly reduced in its natural range, it is unlikely that it will have a great impact on wild stocks of the same species through competition as its habitat is unlikely to be limiting. Past stock enhancement experiments with Atlantic cod in Norway showed that mass release of juvenile hatchery-reared cod had minor effects on potential prey organisms for wild cod (Svåsand *et al*., 2000). Such releases have also been shown to reduce wild cod condition factors and liver index (Fosså *et al*., 1994), further supporting the notion that releases of farmed fish may impact wild populations through competition for food resources.

By following radio-tagged cod, Brooking *et al*. (2006) suggested that escapees from cod farms may increase predation pressure on endangered Atlantic salmon stocks. This notion is further supported by the observations of Wroblewski *et al*. (1996) who tracked radio-tagged farmed cod and found that they associated with wild cod in the ocean and the observations by Hvidsten and Møkkelgjerd (1987) who suggested that natural cod populations consumed ca. 25% of the salmon smolts leaving the Surna River in Norway, further suggesting that escaped cod may also impact wild fish populations.

The behaviour of escaped farmed male cod may encourage interbreeding with wild females as farmed males occupy the same depth whereas wild males occupy deeper areas close to the bottom (Meager *et al*., 2009) and Wroblewski *et al*. (1996) showed that escape cod may migrate to local breeding grounds. However, Skjæraasen *et al*. (2009) found that farmed cod performed poorly against wild cod in sperm competition trials. That being said, using a rare allele as a tracer for farmed cod, Jørstad *et al*. (2008) showed that gametes from farmed fish may produce viable offspring (to the larval stage).

Given the very limited knowledge of such interactions, it is difficult to evaluate the risks associated with cod and other types of finfish culture. That being said, completing the table based on the best available information identifies research gaps that may be addressed. In short, we believe that, for all risks identified, consequences are minor with rare likelihood but that uncertainty is very high in all instances because of a lack of information for each risk. Thus the overall risk associated with each risk is low with very high uncertainty.

4.3.3 Impacts due to fishing for forage fish for fish feed

4.3.3.1 Magnitude of captures

Of the total annual capture fisheries of ca. 90 million tonnes, almost one third of this, or about 30 million tonnes, is typically destined for non-food products, mainly the manufacture of fishmeal and fish oil (FAO Fisheries and Aquaculture Department, 2009). It is the largest landed species group in capture fisheries (Tacon and Metian, 2009a). The most important species in this fishery are mackerel, capelin, blue whiting, Norway pout, anchovy, menhaden, European sprat, herring, sardine, horse mackerel, jack mackerel, and sandeels (Péron *et al*., 2010). The bulk of this production is mainly from Peru (7.6 million tonnes), Chile (3.2 million tonnes), China (2 million tonnes), Iceland (1.3 million tonnes), Japan (1.1 million tonnes), Norway (1 million tonnes), the United States (0.9 million tonnes), Denmark (0.9 million tonnes), Morocco (0.7 million tonnes), South Africa (0.5 million tonnes), and Mexico (0.5 million tonnes) (Péron *et al*., 2010). Of this production, the most important species is by far the Peruvian anchovy, which accounted for about 8.5 million tonnes annual production in 2001–2006 (Péron *et al*., 2010), 7.2 million tonnes of which were fished in Peru, the rest in Chile.

Of the approximately 6 million tonnes of fish meal and 1 million tonne of fish oil produced annually from these directed capture fisheries and other sources (fish by-products, etc.), approximately 50–68% and 80–88% (Bell and Waagbø, 2008; Péron *et al*., 2010; Tacon and Metian, 2008), respectively, are used in the fabrication of aquafeeds for farmed fish. Of this, the proportion of the total of all fish meal and fish oil produced destined for salmon aquafeeds is 15–17% and 43%, respectively, that for trout 6% and 11–13%, respectively, and that for "marine finfish", including cod and seabream, 15–17% and 14–20%, respectively (Tacon and Metian, 2008). It is thought that this great reliance on fishmeal for species farmed in OSPAR countries may thus have a considerable impact on wild stocks of forage fish and the functioning of the ecosystem from which they are fished (e.g., Naylor and Burke, 2005) as, although the proportion of fish products in aquafeeds is declining, the total quantity used is actually increasing because of the growth of the industry (Naylor *et al*., 2009). Péron *et al*.

(2010) suggest that the demand for fish meal and fish oil will increase in coming years. However, this does not necessarily indicate that the requirements for fish meal and fish oil for aquafeeds will be driving the demand. This will come, moreover from increasing demands for direct human consumption and feeding other animals (Tacon and Metian, 2008). A recent analysis of the issue by Tacon and Metian (2008) suggests that the use of fish meal and fish oil by the industry will eventually decrease because of static or decreasing world supplies, increasing price of forage fish because of increasing demands for direct human consumption and for feeding other animals, increasing energy costs, and pressure to ensure sustainability of such fishery resources by consumers.

4.3.3.2 Overview of impacts due to fishing for forage fish for fish feed

The impacts of fishing are complex but quite well studied (e.g., Moore and Jennings, 2000; Turner *et al*., 1999) and various working groups are devoted to understanding such effects, such as the ICES WGECO (working group on ecosystem effects of fishing activities). A thorough analysis of the effects should include consequences resulting from the pathways outlined by the WGCO (ICES, 2007):

- Substratum loss (resuspension through bottom contact of the gear)
- Smothering (resuspension through bottom contact of the gear)
- Change in suspended sediment (resuspension through bottom contact of the gear)
- Change in turbidity (resuspension through bottom contact of the gear)
- Change in sound field (engine noise)
- Change in light regime (resuspension through bottom contact of the gear)
- Visual presence (vessel and/or gear)
- Abrasion/ physical disturbance (interaction with the gear)
- Heavy metal contamination (resuspension through bottom contact of the gear)
- Hydrocarbon contamination (resuspension through bottom contact of the gear)
- Radionuclide contamination (resuspension through bottom contact of the gear)
- Changes in nutrient levels (resuspension through bottom contact of the gear)
- Changes in oxygenation (resuspension through bottom contact of the gear)
- Selective extraction of species (catch)

In short, effects of fishing for the production of fish meal and fish oil may have consequences related to impacts on fish habitat (modification or destruction) or to fish and other species being removed from the ecosystem.

Fishing effects on targeted fish stocks range from insignificant if fish from directed fisheries are not used in the production of fish meal and fish oil for specific aquafeeds through to major if targeted species are fished to beyond sustainable limits. Most fish harvested to produce the raw ingredients used in fish feeds are small pelagic species, most of which are prone to large inter-annual and inter-decadal variation of abundance, especially when fished. Such species typically school and thus may still be fished economically even when their abundance is not great, further contributing to the inter-annual variability and increasing the chance for overexploitation if fisheries for them are not properly managed (Fréon *et al*., 2005). Such heavy exploitation may also lead to some populations of target fishes becoming depleted in some areas for some time with potential impacts for populations of their natural predators as well as other parts of the ecosystem. In contrast, benthic species may not be as prone to schooling, making over-exploitation less likely strictly based on economic principles. Strong fishing pressure may also negatively impact the evolutionary potential of the species as rare alleles, which may be of importance for future adaptation, may be lost (Ryman *et al*., 1995).

Ecosystem-level consequences of fishing fish to produce fish meal and fish oil for aquafeeds may occur because targeted species are often important prey species for many marine predators. Consequences may be divided into pelagic and benthic impacts. The majority of target fishes are pelagics and fisheries directed at these species may be expected to have less long-term impacts on pelagic communities as the physical habitat is not modified and direct impacts on the bottom from this fishery are likely slight, resulting from accidental contacts with fishing equipment with this habitat. For fisheries that target more benthic or suprabenthic species, the impacts on the bottom will be greater and possibly permanent if critical habitat is destroyed.

As the WGEIM does not have the expertise to conduct a thorough review of the relevant literature and various working groups are devoted to understanding such effects (e.g., the ICES WGECO – Working Group on Ecosystem Effects of Fishing Activities), we simply present broad possible consequences of fishing activities on the target fish stocks (Table 3) and ecosystem effects (Table 4) based on the above text. Given that many of the stocks fished are already degraded to some extent and that pressure on them is increasing (Tacon and Metian, 2009b), that there is a long history of overfishing many stocks (Worm *et al*., 2009) and much literature to this end, we suggest that the consequence of this is moderate with a likely likelihood with very low uncertainty, yielding an overall risk of high with very low uncertainty. We feel that the same logic may be used with respect to consequences for the environment and have thus classified them in the same manner.

4.4 Discussion

It is important to note that "risks" as outlined in this document are for unique events; i.e., for effects occurring in a given time period. They do not encompass the risk of effects occurring year after year which, in the long term, may have considerable impacts on communities. So, minor consequences, such as salmon parr from escaped salmon that have reproduced in natural rivers and undergo resource competition with wild salmon parr, may have longer-term cumulative consequences on wild stocks than may be apparent from an evaluation of the results of the qualitative risk assessment described in the current document. Similarly, the current risk assessment also does not scale the overall risk of a given issue (e.g., escaped salmon) through the entire risk sequence. That is, a variety of low and moderate risks at each stage may amount to an overall risk that is somewhat greater than each of its single components.

As discussed, salmonid-related effects are quite well known whereas those for cod and other farmed species are not, highlighting major gaps in information that should be addressed. Overall, consequences identified for escaped salmon typically varied between minor to moderate with low uncertainty and were considered to be rare or else likely. This led the overall risk for each interaction to be either low or moderate. In most cases, uncertainty was low as the interactions are generally well studied. In contrast, the risk associated with interactions for cod and other species were considered to be low but with very high uncertainty as these are poorly or not at all studied. Although much is known of the consequences of fishing for forage species to produce fish meal and fish oil, it was judged that a full assessment on these subjects was beyond the scope of the current working group's mandate and expertise. The direct consequences of fishing for fish meal and fish oil on fish stocks and on ecosystem effects were both considered to be of high overall risk with very low uncertainty given the wealth of information on the subject.

The risk assessment process initiated here provides a framework for standardizing assessments in an objective manner based solely on the knowledge available on a given subject from the literature. This process may be easily expanded to include expert opinion when literature is clearly lacking through the use of on-line surveys and solicitation of input through postings on relevant listservs, etc.

The methods outlined in the current document may be used to assess the risk associated with genetic and disease issues for farmed fish culture. It is presumed that fairly robust synopses have been developed for these and that similar classification schemes could be developed and used to evaluate risk.

In all cases, it is not expected that the severity of consequences in the future will be reduced as escapes will likely not decrease, new species will be cultivated, wild stock are likely to continue to decrease, and pressure on fish stocks that form the basis of the fish meal and fish oil fishery will increase.

Table 4.4.1. Risk register of ecological interactions between escaped fishes from aquaculture on populations and communities of wild fishes of the same or other species and of the impact on target fish stocks and the ecosystem due to fishing for fish to produce fish meal and fish oils for use in aquafeeds based on qualitative measures of consequences and likelihoods for each variable considered. Levels of uncertainty with respect to consequences and likelihoods are given in brackets. Levels of uncertainty are defined in Table 4 and vary from insignificant (1) to minor (2), moderate (3) and major (4). The likelihood of events occurring range from rare (A) to unlikely (B), possible (C), likely (D), and almost certain (E) as outlined in Table 5. Uncertainties associated with a given consequence and likelihood range from very high (VH) to high (H), moderate (M), low (L) and very low (VL) as outlined in Table 6. Overall risks are calculated from the risk analysis matrix presented in Table 7 and range from negligible (N) to low (L), moderate (M), and high (H) with the associated uncertainty being that of the greater of the two associated with consequences and likelihoods. Marine phases for salmon are divided into immediate effects following massive escapes and larger temporal and spatial scale in the oceanic environment.

Risk	Consequence	Likelihood	Risk
<u>**Atlantic salmon (and other related species)**</u>			
<u>Escapes of fish from culture sites (inter-specific interactions)</u>			
Predation on wild fish stocks of other species	2 (VH)	A (VH)	L (VH)
Competition with wild fish stocks (food/space)	2 (VH)	A (VH)	L (VH)
Disease transfer from escaped fish	2 (VH)	A (VH)	L (VH)
<u>Escapes of fish from culture sites (intra-specific interactions)</u>			
Competition for food First freshwater phase	2 (VL)	D (VL)	M (VL)

Marine phase (immediate / oceanic)	2 (VH) / 1 (VL)	A (VH) / A (VL)	L (VH) / N (VL)
Second freshwater phase	2 (VL)	D (VL)	M (VL)
Competition for space			
First freshwater phase	2 (VL)	D (VL)	M (VL)
Marine phase (immediate / oceanic)	2 (VH) / 1 (VL)	A (VH) / A (VL)	L (VH) / N (VL)
Second freshwater phase	3 (VL)	D (VL)	M (VL)
Competition for reproduction			
Second freshwater phase	3 (VL)	D (VL)	M (VL)
Disease transfer from escaped fish			
Marine phase	2 (VH)	A (VH)	L (VH)
Second freshwater phase	1 (VH)	A (VH)	N (VH)
Atlantic cod (and other species likely to spawn in farms)			
Escapes of fish from culture sites (inter-specific interactions)			
Predation on wild fish stocks of other species	2 (VH)	A (VH)	L (VH)
Competition with wild fish stocks (food/space)	2 (VH)	A (VH)	L (VH)
Disease transfer from escaped fish	2 (VH)	A (VH)	L (VH)
Escapes of fish from culture sites (intra-specific interactions)			
Competition for food	2 (VH)	A (VH)	L (VH)
Competition for space	2 (VH)	A (VH)	L (VH)
Competition for reproduction	2 (VH)	A (VH)	L (VH)
Disease transfer from escaped fish	2 (VH)	A (VH)	L (VH)
Use of fish feed in aquaculture			
Impact on fish stocks	3 (VL)	D (VL)	H (VL)
Ecosystem effects of fishing of these species	3 (VL)	D (VL)	H (VL)

4.5 References

Amiro, P.G., 2003. Population status of inner Bay of Fundy Atlantic salmon (*Salmo salar*), to 1999. Can. Tech. Rep. Fish. Aquat. Sci. # 2488: pp. vi + 39.

Asche, F., Roll, K.H., Tveterås, S., 2008. Future trends in aquaculture: productivity growth and increased production. in: Holmer, M., Black, K., Duarte, C.M., Marbà, N., Karakassis, I. (Eds.), Aquaculture in the ecosystem. Springer, pp. 271-292.

Bell, J.G., Waagbø, R., 2008. Safe and nutritious aquaculture produce: benefits and risks of alternative sustainable aquafeeds. in: Holmer, M., Black, K., Duarte, C.M., Marbà, N., Karakassis, I. (Eds.), Aquaculture in the ecosystem. Springer-Link, pp. 185-225.

Black, K.D., Hansen, P.K., Holmer, M., 2008. Salmon Aquaculture Dialogue: working group report on benthic impacts and farm siting (www.worldwildlife.org/aquadialogues). pp. 54.

Black, K.D.E., 2001. Environmental impacts of aquaculture. CRC Press, Boca Raton.

Bridger, C.J., Garber, A.F., 2002. Aquaculture escapement, implications and mitigation: the salmonid case study. in: Costa-Pierce, B.A. (Ed.), Ecological aquaculture: the evolution of the blue revolution. Blackwell Science Ltd., Oxford, pp. 77-102.

Bridger, C.J., Booth, R.K., McKinley, R.S., Scruton, D.A., 2001. Site fidelity and dispersal patterns of domestic triploid steelhead trout (*Oncorhynchus mykiss* Walbaum) released to the wild. ICES J. Mar. Sci. 58, 510-516.

Brooking, P., Doucette, G., Tinker, S., Whoriskey, F.G., 2006. Sonic tracking of wild cod, *Gadus morhua*, in an inshore region of the Bay of Fundy: a contribution to understanding the impact of cod farming for wild cod and endangered salmon populations. ICES J. Mar. Sci. 63, 1364-1371.

Costa-Pierce, B.A., 2002. Ecological aquaculture: the evolution of the blue revolution. Blackwell Publishing, Oxford.

Costello, M.J., 2009. How sea lice from salmon farms may cause wild salmonid declines in Europe and North America and be a threat to fishes elsewhere. Proceedings of the Royal Society B: Biological Sciences. 276, 3385-3394.

Cramon-Taubadel, N.V., Ling, E.N., Cotter, D., Wilkins, N.P., 2005. Determination of body shape variation in Irish hatchery-reared and wild Atlantic salmon. 66, 1471–1482. J. Fish Biol. 66, 1471-1482.

Crawford, C., 2003. Qualitative risk assessment of the effects of shellfish farming on the environment in Tasmania, Australia Ocean Coast. Manage. 46, 47-58.

Cross, T.F., Burnell, G., Coughlan, J., Culloty, S., Dillane, E., McGinnity, P., Rogan, E., 2008. Detrimental genetic effects of interactions between reared strains and wild populations of marine and anadromous fish and invertebrate populations. in: Holmer, M., Black, K., Duarte, C.M., Marbà, N., Karakassis, I. (Eds.), Aquaculture in the ecosystem. Springer, pp. 117-154.

Davenport, J., Black, K., Burnell, G., Cross, T., Culloty, S., Ekarante, S., Furness, B., Mulcahy, M., Thetmeyer, H., 2003. Aquaculture: the ecological issues. Blackwell Publishing, Oxford.

Einum, S., Fleming, I.A., 1997. Genetic divergence and interactions in the wild among native, farmed and hybrid Atlantic salmon. J. Fish Biol. 50, 634-651.

Einum, S., Fleming, I.A., 2001. Implications of stocking: ecological interactions between wild and released salmonids. Nordic Journal of Freshwater Research. 75, 56-70.

Eriksson, T., Eriksson, L.O., 1991. Spawning migratory behaviour of coastal-released Baltic salmon (*Salmo salar*). Effects on straying frequency and time of river ascent. Aquaculture. 98, 79-87.

FAO Fisheries and Aquaculture Department, 2009. FAO yearbook - world fisheries and aquaculture statistics - 2007. pp. xxiv + 73.

FAO Fisheries and Aquaculture Department, 2010. Global datasets, FishStat Plus - Universal software for fishery statistical time series. http://www.fao.org/fishery/statistics/software/fishstat/en. Access date: March 22, 2010.

Fiske, P., Lund, R.A., Hansen, L.P., 2006. Relationships between the frequency of farmed Atlantic salmon, *Salmo salar* L., in wild salmon populations and fish farming activity in Norway, 1989-2004. ICES J. Mar. Sci. 63, 1182-1189.

Fiske, P., Lund, R.A., Østborg, G.M., Fløystad, L., 2001. Escapees of reared salmon in coastal and riverine fisheries in the period 1989-2000. NINA Oppdragsmelding. 704, 1-26.

Fleming, I.A., Einum, S., 1997. Experimental tests of genetic divergence of farmed from wild Atlantic salmon due to domestication. ICES J. Mar. Sci. 54, 1051-1063.

Fleming, I.A., Jonsson, B., Gross, M.R., 1994. Phenotypic divergence of sea-ranched, farmed, and wild salmon. Can. J. Fish. Aquat. Sci. 51, 2808-2824.

Fleming, I.A., Hindar, K., Mjolnerod, I.B., Jonsson, B., Balstad, T., Lamberg, A., 2000. Lifetime success and interactions of farm salmon invading a native population. Proceedings of the Royal Society B: Biological Sciences. 267, 1517-1523.

Ford, J.S., Myers, R.A., 2008. A global assessment of salmon aquaculture impacts on wild salmon, PLoS Biology.

Fosså, J.H., Nordeide, J.T., Salvanes, A.G.V., Smedstad, O., 1994. Impacts of released cod on wild fish populations in Masfjorden, western Norway. Aqucult. Fish. Manage. 25 (Suppl. 1), 35-48.

Fréon, P., Cury, P., Shannon, L.A., Roy, C., 2005. Sustainable exploitation of small pelagic fish stocks challenged by environmental and ecosystem changes: a review. Bull. Mar. Sci. 76, 385–462.

Grant, S.M., Brown, J.A., Boyce, D.L., 1998. Enlarged fatty livers of small juvenile cod: a comparison of laboratory-cultured and wild juveniles. J. Fish Biol. 52, 1105-1114.

Hansen, L.P., 2006. Migration and survival of farmed Atlantic salmon (*Salmo salar* L.) released from two Norwegian fish farms. ICES J. Mar. Sci. 63, 1211-1217.

Hansen, L.P., Jonsson, B., 1991. The effect of timing of Atlantic salmon smolt and post-smolt release on the distribution of adult returns. Aquaculture. 98, 61-67.

Hansen, L.P., Jacobsen, J.A., 2003. Origin and migration of wild and escaped farmed Atlantic salmon, *Salmo salar* L., in oceanic areas north of the Faroe Islands. ICES J. Mar. Sci. 60, 110-119.

Hansen, L.P., Døving, K.B., Jonsson, B., 1987. Migration of farmed Atlantic salmon with and without olfactory sense, released on the Norwegian coast. J. Fish Biol. 30, 713-721.

Hard, J.J., Berejikian, B.A., Tezak, E.P., Schroder, S.L., Knudsen, C.M., Parker, L.T., 2000. Evidence for morphometric differentiation of wild and captively reared adult coho salmon: a geometric analysis. Environ. Biol. Fish. 58: 61–73. Environ. Biol. Fish. 58, 61-73.

Hargrave, B., 2005. Environmental effects of marine finfish aquaculture. Springer, Berlin.

Heggberget, T.G., Økland, F., Ugedal, O., 1993. Distribution and migratory behaviour of adult wild and farmed Atlantic salmon (*Salmo salar*) during return migration. Aquaculture. 118, 73-83.

Hindar, K., Fleming, I.A., McGinnity, P., Diserud, O., 2006. Genetic and ecological effects of salmon farming on wild salmon: modelling from experimental results. ICES J. Mar. Sci. 63, 1234-1247.

Holmer, M., Black, K., Duarte, C.M., Marbà, N., Karakassis, I., 2008. Aquaculture in the ecosystem. Springer.

Hvidsten, N.A., Møkkelgjerd, P.I., 1987. Predation on salmon smolts, *Salmo salar* L., in the estuary of the River Surna, Norway. J. Fish Biol. 30, 273-280.

ICES, 2007. Report of the Working Group on Ecosystem Effects of Fishing Activities (WGECO), 11–18 April, 2007, Copenhagen Denmark. ICES CM 2007/ACE:04: pp. 195.

ICES WGNAS, 2010. Incidence of escapee farmed salmon in coastal areas and rivers of the northe east Atlantic.

Jacobsen, J.A., Hansen, L.P., 2001. Feeding habits of wild and escaped farmed Atlantic salmon, *Salmo salar* L., in the Northeast Atlantic. ICES J. Mar. Sci. 58, 916-933.

Jonsson, B., 1997. A review of ecological and behavioural interactions between cultured and wild Atlantic salmon. ICES J. Mar. Sci. 54, 1031-1039.

Jonsson, B., Jonsson, N., 2004. Factors affecting marine production of Atlantic salmon (*Salmo salar*). Can. J. Fish. Aquat. Sci. 61, 2369-2383.

Jonsson, B., Jonsson, N., 2006. Cultured Atlantic salmon in nature: a review of their ecology and interaction with wild fish. ICES J. Mar. Sci. 63, 1162-1181.

Jonsson, B., Jonsson, N., Hansen, L.P., 1990. Does juvenile experience affect migration and spawning of adult Atlantic salmon? Behavioral Ecology and Sociobiology. 26, 225-230.

Jonsson, N., Hansen, L.P., Jonsson, B., 1993. Migratory behaviour and growth of hatchery-reared post-smolt Atlantic salmon, *Salmo salar* L. J. Fish Biol. 42, 435-443.

Jonsson, N., Hansen, L.P., Jonsson, B., 1994. Juvenile experience influences timing of adult river ascent in Atlantic salmon. Anim. Behav. 48, 740-742.

Jørstad, K.E., van der Meeren, T., Paulsen, O.I., Thomsen, T., Thorsen, A., Svåsand, T., 2008. "Escapes" of eggs from farmed cod spawning in net pens: recruitment to wild stocks. Rev. Fish. Sci. 16, 285-295.

Kjesbu, O.S., Witthames, P.R., 2007. Evolutionary pressure on reproductive strategies in flatfish and groundfish: Relevant concepts and methodological advancements. J. Sea Res. 58, 23-34.

Klemetsen, A., Amundsen, P.A., Dempson, J.B., Jonsson, B., Jonsson, N., O'Connell, M.F., Mortensen, E., 2003. Atlantic salmon *Salmo salar* L., brown trout *Salmo trutta* L. and Arctic charr *Salvelinus alpinus* (L.): A review of aspects of their life histories. Ecology of Freshwater Fish. 12, 1-59.

Kostow, K.E., 2004. Differences in juvenile phenotypes and survival between hatchery stocks and a natural population provide evidence for modified selection due to captive breeding. Can. J. Fish. Aquat. Sci. 61, 577-589.

Kristiansen, T.S., Ottera, H., Svasand, T., 2000. Size-dependent mortality of juvenile Atlantic cod, estimated from recaptures of released reared cod and tagged wild cod. J. Fish Biol. 56, 687-712.

Lacroix, G.L., Knox, D., 2005. Distribution of Atlantic salmon (*Salmo salar*) postsmolts of different origins in the Bay of Fundy and Gulf of Maine and evaluation of factors affecting migration, growth, and survival. Can. J. Fish. Aquat. Sci. 62, 1363-1376.

Leggatt, R., O'Reilly, P., Blanchfield, P.J., McKindsey, C.W., Devlin, R.H., in press. Pathway of effects of escaped aquaculutre organisms or their reproductive material on natural ecosystems in Canada. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/XXX.

Lund, R.A., Økland, F., Hansen, L.P., 1991. Farmed Atlantic salmon (*Salmo salar*) in fisheries and rivers in Norway. Aquaculture. 98, 143-150.

McGinnity, P., Prodöhl, P., Ferguson, A., Hynes, R., Maoiléidigh, N.Ó., Baker, N., Cotter, D., O'Hea, B., Cooke, D., Rogan, G., Taggart, J., Cross, T., 2003. Fitness reduction and potential extinction of wild populations of Atlantic salmon, *Salmo salar*, as a result of interactions with escaped farm salmon. Proceedings of the Royal Society B: Biological Sciences. 270, 2443-2450.

Meager, J.J., Skjæraasen, J.E., Fernö, A., Karlsen, Ø., Løkkeborg, S., Michalsen, K., Utskot, S.O., 2009. Vertical dynamics and reproductive behaviour of farmed escapee and wild cod (*Gadus morhua*). Mar. Ecol. Prog. Ser. 389, 233-243.

Moe, H., Dempster, T., Sunde, L.M., Winther, U., Fredheim, A., 2007. Technological solutions and operational measures to prevent escapes of Atlantic cod (*Gadus morhua*) from sea cages. Aquac. Res. 38, 91-99.

Moore, G., Jennings, S., 2000. Commercial fishing: the wider ecological impacts. Cambridge University Press.

Morton, A., Volpe, J.P., 2002. A description of escaped farmed Atlantic salmon *Salmo salar* captures and their characteristics in one Pacific salmon fishery area in British Columbia, Canada, in 2000. Alaska Fishery Research Bulletin. 9, 102-110.

Naylor, R., Burke, M., 2005. Aquaculture and ocean resources: raising tigers in the sea. Ann. Rev. Environ. Resour. 30, 185–218.

Naylor, R., Hindar, K., Fleming, I.A., Goldberg, R., Williams, S., Volpe, J., Whoriskey, F., Eagle, J., Kelso, D., Mangel, M., 2005. Fugitive salmon: assessing the risks of escaped fish from net-pen aquaculture. BioSci. 30, 427-437.

Naylor, R.L., Goldburg, R.J., Primavera, J.H., Kautsky, N., Beveridge, M.C.M., Clay, J., Folke, C., Lubchenco, J., Mooney, H., Troell, M., 2000. Effect of aquaculture on world fish supplies. Nature. 405, 1017-1024.

Naylor, R.L., Hardy, R.W., Bureau, D.P., Chiu, A., Elliott, M., Farrell, A.P., Forster, I., Gatlin, D.M., Goldburg, R.J., Hua, K., Nichols, P.D., 2009. Feeding aquaculture in an era of finite resources. Proc. Nat. Acad. Sci. U. S. A. 106, 15103-15110.

Nødtvedt, M., Fernø, A., Steingrund, P., Gjøsæter, J., 1999. Anti-predator behaviour of hatchery-reared and wild Atlantic cod (*Gadus morhua* L.), and the effect of predator training. in: Howell, B.R., Moksness, E., Svåsand, T. (Eds.), Stock Enhancement and Sea Ranching. Blackwell Science Ltd, pp. 350-362.

Nordeide, J.T., Salvanes, A.G.V., 1991a. Observations on reared nearly released and wild cod (*Gadus morhua* L.) and their potential predators. ICES Mar. Sci. Symp. 192, 139-146.

Nordeide, J.T., Salvanes, A.G.V., 1991b. Observations on reared nearly released and wild cod (*Gadus morhua* L.) and their potential predators. ICES Mar. Sci. Symp. 192, 139-146

Norwegian Fisheries Directorate, 2009. Escaping of salmonids from fish farms. http://www.fiskeridir.no/fiskeridir/statistikk/akvakultur/statistikk-for-akvakultur. Access date: April 8, 2010.

Økland, F., Heggberget, T.G., Jonsson, B., 1995. Migratory behaviour of wild and farmed Atlantic salmon (*Salmo salar*) during spawning. J. Fish Biol. 46, 1-7.

Péron, G., François Mittaine, J., Le Gallic, B., 2010. Where do fishmeal and fish oil products come from? An analysis of the conversion ratios in the global fishmeal industry. Marine Policy. 34, 815-820.

Power, J.H., McCleave, J.D., 1980. Riverine movements of hatchery reared Atlantic salmon (*Salmo salar*) upon return as adults. Environ. Biol. Fish. 5, 3-13.

Ryman, N., Utter, F., Laikre, L., 1995. Protection of intraspecific biodiversity of exploited fishes. Rev. Fish Biol. Fisheries. 5, 417-446.

Salvanes, A.G.V., Braithwaite, V., 2006. The need to understand the behaviour of fish reared for mariculture or restocking. ICES J. Mar. Sci.

Skilbrei, O., Wennevik, V., 2006. The use of catch statistics to monitor the abundance of escaped farmed Atlantic salmon and rainbow trout in the sea. ICES J. Mar. Sci. 63, 1190-1200.

Skjæraasen, J.E., Mayer, I., Meager, J.J., Rudolfsen, G., Karlsen, Ø., T., H., Kleven, O., 2009. Sperm characteristics and competitive ability in farmed and wild cod. Mar. Ecol. Prog. Ser. 375, 219-228.

Soto, D., Arismendi, I., González, J., Sanzana, J., Jara, F., Jara, C., Guzman, E., Lara, A., 2006. Southern Chile, trout and salmon country: Invasion patterns and threats for native species. Rev. Chil. Hist. Nat. 79, 97-117.

Steingrund, P., Fernø, A., 1997. Feeding behaviour of reared and wild cod and the effect of learning: two strategies of feeding on two-spotted gobies. J. Fish Biol. 51, 334-348.

Stickney, R.R., McVey, J.P.E., 2002. Responsible Marine Aquaculture. CABI Publishing, Wallingford.

Svåsand, T., Kristiansen, T.S., Salvanes, A.G.V., Engelsen, R., 2000. The enhancement of cod stocks. Fish and Fisheries. 1, 173-205.

Tacon, A.G.J., Metian, M., 2008. Global overview on the use of fish meal and fish oil in industrially compounded aquafeeds: Trends and future prospects. Aquaculture. 285, 146-158.

Tacon, A.G.J., Metian, M., 2009a. Fishing for feed or fishing for food: Increasing global competition for small pelagic forage fish. Ambio. 38, 294-302.

Tacon, A.G.J., Metian, M., 2009b. Fishing for aquaculture: non-food use of small pelagic forage fish-a global perspective. Rev. Fish. Sci. 17, 305-317.

Thorpe, J.E., 2004. Life history responses of fishes to culture. J. Fish Biol. 65 (suppl. A), 263-285.

Thorstad, E.B., Heggberget, T.G., Økland, F., 1998. Migratory behaviour of adult wild and escaped farmed Atlantic salmon, Salmo salar L., before, during and after spawning in a Norwegian river. Aquac. Res. 29: 419–428. Aquac. Res. 29, 419-428.

Thorstad, E.B., Fleming, I.A., McGinnity, P., Soto, D., Wennevik, V., Whoriskey, F., 2008. Incidence and impacts of escaped farmed Atlantic salmon *Salmo salar* in nature. NINA Special Report 36: pp. 110.

Turner, S.J., Thrush, S.F., Hewitt, J.E., Cummings, V.J., Funnell, G., 1999. Fishing impacts and the degradation or loss of habitat structure. Fisheries Management and Ecology. 6, 401-420.

Weir, L.K., Fleming, I.A., 2006. Behavioural interactions between farm and wild salmon: potential for effects on wild populations. in: Fisheries and Oceans Canada (Ed.), A scientific review of the potential environmental effects of aquaculture in aquatic ecosystems. Canadian Technical Report of Fisheries and Aquatic Sciences 2450, Vol V, pp. 1-29.

Weir, L.K., Hutchings, J.A., Fleming, I.A., Einum, S., 2004. Dominance relationships and behavioural correlates of individual spawning success in farmed and wild male Atlantic salmon, *Salmo salar*. J. Anim. Ecol. 73, 1069-1079.

Whoriskey, F., Brooking, P., Doucette, G., Tinker, S., Carr, J., 2006. Movements and fate of sonically tagged farmed Atlantic salmon released in Cobscook Bay, Maine, USA. ICES J. Mar. Sci. 63, 1218-1223.

Worm, B., Hilborn, R., Baum, J.K., Branch, T.A., Collie, J.S., Costello, C., Fogarty, M.J., Fulton, E.A., Hutchings, J.A., Jennings, S., Jensen, O.P., Lotze, H.K., Mace, P.M., McClanahan, T.R., Minto, C., Palumbi, S.R., Parma, A.M., Ricard, D., Rosenberg, A.A., Watson, R., Zeller, D., 2009. Rebuilding Global Fisheries. Science. 325, 578-585.

Wroblewski, J.S., Smedbol, R.K., Taggart, C.T., Goddard, S.V., 1996. Movements of farmed and wild Atlantic cod (*Gadus morhua*) released in Trinity Bay, Newfoundland. Mar. Biol. 124, 619-627.

Youngson, A.F., Dosdat, A., Saroglia, M., Jordan, W.C., 2001. Genetic interactions between marine finfish species in European aquaculture and wild conspecifics. J. Appl. Ichthyol. 17, 153-162.

5 ToR i) Report to SSGHIE on plans to promote cooperation between EGs covering similar scientific issues

5.1 Joint meeting between WGEIM and WGMASC

Both the WGEIM and the WGMASC have established that there is considerable overlap in Terms of Reference they presently work on. Past and current overlapping ToRs are presented in Table 5.1.1. To address this question a joint meeting was organised and hosted by Francis O'Beirn, member of both groups. The first day of the meeting was devoted to discussing the overlap and develop ways to deal with this during the remainder of the coinciding meetings and in the future (Annex 2).

Table 5.1.1. ToRs overlapping between WGMASC and WGEIM

WGEIM	WGMASC
(ToR a) Evaluate the examples of sustainability indices proposed for mariculture activities and critically evaluate those SI's recommended by WGEIM and other fora (started in 2005)	(ToR e) Develop a work plan to evaluate the current sustainability of shellfish culture and identify options to improve sustainability (2003 and 2004) (ToR b) Develop a recommended framework for the integrated evaluation of the impacts of shellfish aquaculture activities in the coastal zone (2006–2009)
(ToR b) Investigate and report on fouling hazards associated with the physical structures used in mariculture with a view to developing integrated pest management strategies (started in 2006)	(ToR d) Review and assess: the potential for transfer of non-indigenous species and diseases; the potential genetic implications for wild stocks; the impact on recruitment to existing stocks by large-scale transfers, and scientific tools for decision support on cultured shellfish transfer issues (started in 2008)
(ToR d) Review and report on the use of seed stock quality criteria in mariculture and their applications in term of ecological performance (started in 2008)	(ToR a) Provide a synthesis on the development of hatcheries, the proportion of cultured animals to wild conspecifics and the relative proportion of triploids and other selected strains produced by hatcheries (2003–2005) (ToR c) Prepare a report assessing the utility of hatchery reared seed to enhance wild scallop fisheries with the view of improving the management of this resource (2006–2007)
(ToR e) Assess the potential impact of climate change on aquaculture activities relevant to each ICES member state (started in 2009)	(ToR e) Review the state of knowledge of the evidence for and effect of climate change on shellfish aquaculture distribution and production in ICES and countries worldwide (started in 2008)

It was decided that, for the 2010 meeting, members from WGMASC and WGEIM would sit-in on discussions of the other group. Peter Cranford and Joseph Mazurie gave input to the WGEIM ToR a). Joseph proposed the group to examine the document "EVAD guide" for building sustainability indicators and evaluating aquaculture sustainability:

(http://www.inra.fr/coordination_piscicole/groupes_de_travail/systeme_d_elevage/evad)

Pauline Kamermans discussed WGEIM ToR d) with some members of the WGEIM. WGEIM did not work on ToR e) in 2010, but Matt Gubbins provided a report of his institute on effects of climate change on aquaculture that has some reference to shellfish to WGMASC. Chris McKindsey gave an overview of work done in the framework of WGEIM ToR b) when WGMASC was discussing ToR d). And Thomas Landry gave input to WGMASC ToR f).

A general discussion was held on the roles of WGEIM and WGMASC within ICES. Four options were identified:

1) Leave things as they are with overlap in ToRs and limited direct cooperation.
2) WGMASC to focus on shellfish aquaculture husbandry and WGEIM to focus on environmental impacts of shellfish aquaculture.
3) WGMASC to focus on bivalves and WGEIM to focus on finfish.

4) Increase cooperation between WGMASC and WGEIM through joint meetings.

All options were considered. There was consensus that option 1 was not desirable. Option 2 poses problems for WGMASC as current shellfish husbandry cannot be viewed without giving attention to the environmental impacts. Option 3 has two complications: (1) what to do with Integrated Multi Trophic Aquaculture that includes both shellfish and finfish as well as algae, and (2) most presently active members of WGEIM have a shellfish background. Thus, it was agreed that option 4 is the most favourable one. In order to execute this it was proposed to have joint meetings every 3 years. In the meantime the chairs of both groups will stay in close contact through teleconferencing and videoconferencing about the ToRs being worked on to identify any overlaps. If this is the case they can then invite key members of the respective group to the annual meetings to work on the ToRs together or else address the specific ToR at future joint meetings. In addition, chairs will exchange draft reports immediately after their respective meetings and ask key members of their group to review the text on related ToRs.

5.2 Cooperation with other EGs of SSGHIE

WGEIM and WGMASC looked through the SSGHIE expert group list (and more widely) with a view to identifying those where there had been previous instances of collaboration and where there may be potential for collaborative activity in the future (Table 5.2.2).

Table 5.2.2. Overview of EGs with which WGEIM / WGMASC has had collaboration and those with which the WGs would envisage possible future interactions.

	Worked before?	Interested in joint activity?	Joint meeting potential?
WGPDMO	Y WGEIM	Y	Y
MCWG	N	Y	N
MSWG	N	Y	N
ICZM	Y WGEIM	Y	Y
SGONS	N	N	N
WGMASC	Y	Y	Y
WGEIM	Y	Y	Y
WGHABD	N	Y	N
WGEXT	N	N	N
WGFCCIFS	N	Y	N
WGAGFM	Y WGEIM	Y	N
WGBEC	N	Y (WGEIM)	N
WKIMM	N	Y	N
BEWG	N	Y	N
WGITMO	N	Y	N
WGNAS	Y WGEIM	Y	N
EuroShell		Y	N

WGPDMO: WGEIM are currently working with WGPDMO on the OSPAR request on impacts on fisheries. WGMASC regularly refers to documents from the group and sent recommendations to them. Common issues are climate change, transfer of shellfish seed / seed quality. There is potential to swap experts between groups when relevant ToRs arise.

MCWG: Potential interaction with WGEIM on monitoring chemical releases from finfish farms.

MSWG: Overlap with WGEIM on chemical contaminants from aquaculture in sediments.

ICZM: This group was formed from activity of WGEIM and is relevant to both groups, particularly sustainability indicators and MSP. Both groups deal with aquaculture aspects of ICZM.

WGHABD: Potential interaction with WGMASC on interactions of HAB toxins on cultured shellfish and WGEIM on HAB effects on farmed fish.

WGFCCIFS – This workshop activity may have already ceased, but groups may have been interested in outputs from both groups on climate change / aquaculture issues.

AGFM – WGEIM are currently working with this group on OSPAR request. There is potential future for interaction with MASC on transfer of shellfish stock ToR.

WGBEC: There is common ground with WGEIM on effects of contaminant discharges from finfish farms.

The groups noted that interactions on socio-economic aspects were largely missing, but that two ICES workshops - WKIMM (Introducing coupled ecological-economic modelling and risk assessment into management tools) and WKSECRET (..) were addressing this topic. The WGs felt that the output of these workshops and the history of how these workshops were initiated may be relevant.

WGIMTO – This group has produced risk assessments on transfer of organisms that have been of relevance to MASC and WGEIM.

BEWG – There is common ground between this group and both WGEIM and WGMASC on benthic interactions with fish / shellfish farming.

WGNAS – North Atlantic Salmon. WGEIM are working with this group this year on the OSPAR request on impacts of mariculture on fisheries.

EuroShell – This EAS group looking at aspects of shellfish culture has close interaction with WGMASC members.

5.3 Importance of aquaculture

Total production from capture fisheries has remained fairly constant since the late 1980s at about 90 million tonnes annually. In contrast, aquaculture production is increasing world-wide, growing from accounting for 3.2% of the total fisheries production in 1950 to 43% of the total in 2008, including 47% of the total fisheries production destined for human consumption (Figure 5.3.1). This marked increase in production from aquaculture has allowed total fisheries production to increase nearly linearly since 1950 at a rate of about 2.4 million tonnes per year to a record production of 159.1 million tonnes in 2008 (FAO Fisheries and Aquaculture Department 2009). The FAO also suggests that this trend will likely continue in the future, although the rate of growth of aquaculture production is slowing down. Within ICES member nations, growth in total fisheries production has been in decline since 1988, when it reached a maximum of 29.7 million tonnes, to 20.7 million tonnes in 2008 (Figure 5.3.2). Of this total, the absolute and proportional contribution from aquaculture has grown steadily over this period and in 2008 accounted for 2.7 million tonnes, or 13 % of the total fisheries production. A number of ICES nations have also stated that they have ambitious targets for increasing aquaculture production in the future and thus the importance of this activity will only grow in the future. Together, this highlights the current and growing importance of ICES EGs that address aquaculture issues, such as the WGEIM and the WGMASC.

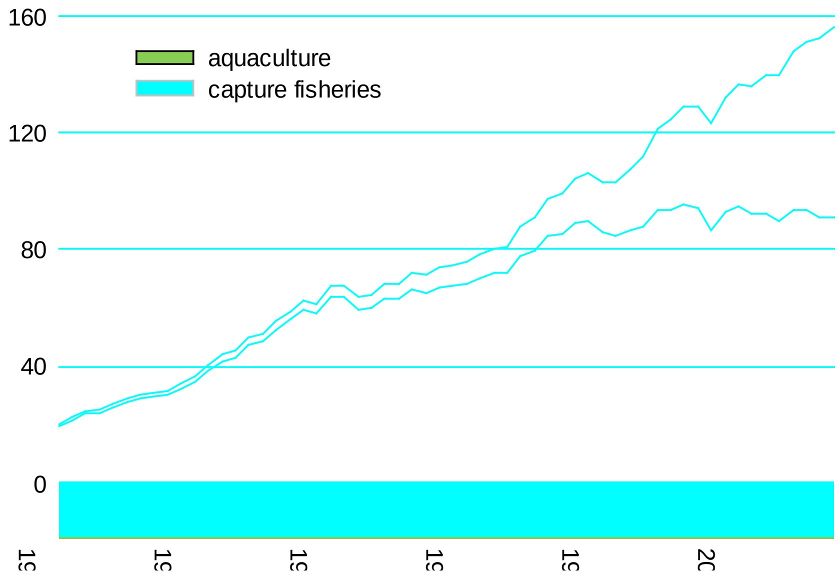


Figure 5.3.1. Global fisheries and aquaculture production (data from FAO, 2010), 1950–2008. Note that the proportion of aquaculture production of the total of fisheries production destined from human consumption accounted 47% in 2008 and surpassed 50% in 2009.

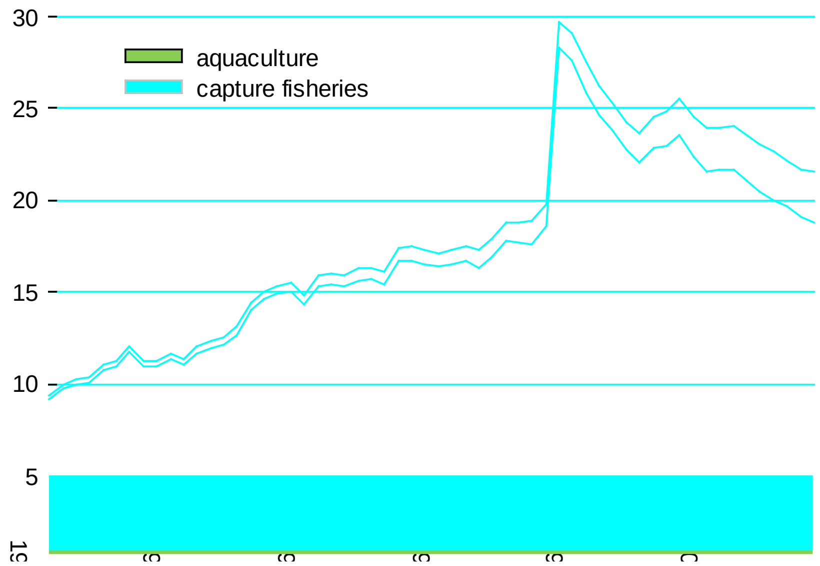


Figure 5.3.2. Fisheries and aquaculture production by ICES member nations (data from FAO, 2010), 1950–2008. Note that the important increase in 1988 represents the addition of data from the Russian Federation and other Eastern Block countries. Landings from capture fisheries have decreased thereafter whereas those from aquaculture have increased.

6 ToR j) Joint ICES WGMASC and WGEIM Comments on Draft Document: "Environmental and Social Standards for Bivalve Aquaculture" prepared by the World Wildlife Fund Bivalve Aquaculture Dialogue (1 February 2010)

The joint 2010 meeting of the WGMASC and WGEIM included a discussion on this document and the comments below reflect the general scope of these discussions. The WWF standards outlined in this document are designed to minimize key social and environmental issues associated with shellfish farming while permitting the industry to remain economically viable. Overall, the WGEIM and WGMASC (hereafter, "the groups") support the WWF initiative to establish codes of good conduct for all types of aquaculture, including bivalve aquaculture. Such initiatives can provide incentives to promote a sustainable aquaculture industry and consumer confidence. Both ICES expert groups have provided advice on the evaluation of the effects of shellfish aquaculture activities in previous annual reports and numerous other ICES groups have provided guidelines on methodologies for the evaluation of human impacts in the marine environment.

Some of our comments on the WWF Bivalve Aquaculture Dialogue (BAD) certification standards (herein defined as "the standards") rely on the WGMASC recommended framework for the integrated management of shellfish aquaculture (WGMASC, 2009) as a means of comparing our previous recommendations with the content of the WWF standards. It is recognized that the management framework recommended by the WGMASC and the WWF BAD differ fundamentally in that the former represents a potential governance-approach to ensuring sustainable culture practices for potential use by regulatory agencies while the latter takes a market-based approach with the associated costs largely borne by industry. Although both approaches share many of the same principles, we recognize that a cost-effective approach is needed to provide smaller operators and less developed countries with an opportunity to obtain certification.

Certification schemes for shellfish culture need to cover all the aspects of ecosystem-based management, including considerations of the social, economic and environmental impact. The WGMASC (2009) framework recommended an ecosystem approach be taken to aquaculture management that is comprehensive and based on the best available scientific knowledge of the ecosystem and its dynamics. Actions are designed to be taken on the influences of aquaculture developments that are critical to the health of ecosystems, thereby achieving sustainable use of ecosystem goods and services and maintenance of ecosystem integrity.

Ecosystem interactions with bivalve aquaculture are well known to be highly complex and both positive and negative environmental effects can occur simultaneously as a result of bivalve husbandry practices. The groups thought that the standards do not fully encompass the complexities of the interactions between bivalve culture and the environment. For example, the potential for some positive effects on biodiversity due to bottom culture are not also considered for off-bottom culture. In addition, it was recognized by the groups that aquaculture is typically not the sole stressor in areas where bivalve culture is conducted and that these too must also be addressed and considered when evaluating the influence of bivalve culture in the environment. For example, the potential for a positive net cumulative effect of different human activities, such as mitigation of eutrophication through the introduction of bivalve filter feeders, are not included in the analysis of the effects of culture sites.

The WWF standards represent a simplified ecosystem-based approach in which performance standards were developed to address a reduced subset of environmental issues (particularly Principles 2, 3 and 4) that were identified as being critical during the open WWF BAD dialogue process. Again, this excludes many ecosystem services that the cultured bivalves provide that may mitigate the specific negative effects identified during the dialogue process. While it can be assumed that cost considerations for small aquaculture operations were instrumental in the development of this simplified approach, the rationale for omitting a wide range of known environmental interactions with bivalve culture (both positive and negative) should be more fully described in the preamble to the standards document.

The WGMASC (2009) recommendations noted that "it is essential that the development of a management framework should be inclusive with diverse stakeholder participation, transparency and communication." Although science has an important role in advising managers and policy-makers on the ecological consequences related to available management options, sustainability decisions need to be made within a framework that is both science- and ecosystem-based, but which also incorporates societal values. The WWF standards were developed based on wide stakeholder participation in multiple dialogue workshops and in the global decision-making body. The open participatory approach utilized by the WWF, which included science input at all stages, was an iterative multi-stakeholder process that provided an outcome that reflects this diverse input. Although scientists can identify areas for improvement, we also respect the fact that the recommended process was followed for the development of the standards and that the outcome reflects both science and socio-economic perspectives. Nonetheless, there was a concern from some members within the groups that the Bivalve Aquaculture Dialogue process in general did not fully consider social issues with respect to setting standards for sustainability. There were concerns that the application of the standards could be used as a mechanism by which producers that do not wish to subscribe to the standards (whether they would meet them or not) could be negatively affected due to public perception. The groups acknowledge the stated goal of the authors to achieve bay-wide compliance and participation in the programme. however, this goal may not be practical. Consequently, non-subscription by some producers within an area may have implications on adjacent or near-by producers that may wish to apply for standardization. An example of an attempt to consider social issues with respect to setting standards for sustainability is the EVAD programme (Guide to the co-construction of sustainable development indicators in aquaculture) developed by INRA with IFREMER contribution[1]. Indicators must be developed by various stakeholders based on substantial feedback, evaluated, and reformulated as needed to address the 'local' issues of concern.

The groups noted that the draft standards show inconsistencies with respect to the approach and quantitative nature described for assessing the different principles and criteria. Some standards are very specific with defined thresholds whereas others are more directional. For example, limits for sulphides under some circumstances are set at 3000 μm whereas other risks are suggested to be manageable "with appropriate designs and monitoring".

A large focus of our discussions was on Principle 2 of the standards (Avoid, remedy or mitigate significant adverse effects on habitats, biodiversity, and ecological processes). This principal was seen by the groups as both the strength and weakness of

[1] http://www.inra.fr/coordination_piscicole/groupes_de_travail/systeme_d_elevage/evad

the document. It provides clear limits on two metrics to which producers must adhere. The groups acknowledged that this broad approach has been recommended in the past by ICES for a number of topics, and is correctly applied in the development of these standards. However, it was thought by some members within the groups that the suggested limits are too prescriptive (i.e., the setting of very precise limits for certain metrics applied on a global scale) whereas others though that a good balance was met and this approach has been recommended numerous times by ICES for a number of topics. Although limits are needed to make any standard a standard, some members of the groups thought that there should be increased flexibility in the proposed standards to make allowances for regional or site-specific realities of culture sites in some areas. That being said, specific methods that are being used regionally and that show equivalent levels of condition of the environment are admissible to be used in lieu of prescribed metrics where available and, as such, the prescriptive nature of the principle is offset by this in some way.

The link between sediment organic loading and benthic communities and chemical indicators, such as sulphides, is well established and the latter may be used to monitor the degree of organic loading. A single indicator of the potential effects of seabed organic enrichment on benthic habitat and communities was identified (total 'free' sulphide). This indicator was recommended by the WGMASC (2009), but in conjunction with supporting information by other indicators. The use of at least two environmental performance indicators was encouraged to address this issue as a precaution towards preventing erroneous certification decisions. It was noted that the indicator of impact due to organic enrichment does not respond solely to biodeposition from bivalve aquaculture. The monitoring programme associated with this document has yet to be made available and so the group cannot comment on this aspect of the document. It was generally recognized that this may be one of the most important aspects in this process. As written, it is difficult to assign cause and effect based on available sampling approaches for evaluating benthic effects. Off-bottom sites are often located in the deepest areas of culture areas; locations that are also naturally the richest in organic material as they are often depositional in nature. Therefore, sampling reference (control) sites located outside of the aquaculture site(s) is potentially confounded. In addition, plankton depletion by farms may occur over large spatial scales such that sedimentation rates outside of farms are decreased below the normal values. This would result in decreasing organic loading outside of farm areas and decreased sulphide levels, further confounding comparison between farm sites and reference sites. The farm monitoring program design is critical and the standards cannot be practically implemented until a consensus is reached on the applicability and scientific effectiveness of the selected design. Some additional considerations in deriving the design of sampling methodologies include:

- Geographic and topographic location (e.g. Rias, Fjords, bays, estuaries…);
- Seasonal and spatial variation in an indicator;
- Sampling intensity required to prevent type I and II statistical errors in different environments;
- Scientific peer review of the monitoring program is an essential step in this process.

Some discussion by the groups focused on using alternate indices of phytoplankton depletion. One suggestion was the use of meat yield of farmed bivalves based on the logic that the farmers want this maximized to ensure the greatest return on their investment. This approach focuses on the product itself, the production of which requires good growing conditions including adequate food supply and quality of water. This approach may help address systems that are organically enriched and within which primary productivity and standing stock are great enough to support the proposed biomass of bivalves in the system. However, it was felt that bivalve growth and stock yield is responsive to numerous environmental variations that vary over temporal and spatial scales, and every producer would not be open to sharing meat yield data. In addition, the methods needed to evaluate this indicator and make clear cause-effect links to environmental condition have not been developed. Again, scientific peer review of these proposed monitoring approaches is essential in this process.

A comparison of the current certification standards with other similar documents (e.g., the draft WWF Salmon Aquaculture Dialog - SAD) suggests that the indices selected for bivalve certification are relatively restricted. In contrast, bivalve culture is arguably much more complex in terms of its interactions with the environment than is fish cage farming. The SAD has been ongoing for some time and yet the BAD is moving forward with insufficient time to comment on it appropriately. Similarly, additional time is needed to evaluate the effectiveness of benthic effect monitoring protocols when they become available. Although the current BAD process had an extensive outreach component to seek input from various groups during its development, some members in the groups were not aware of the dialogue until very recently. It was felt that the process is moving too quickly for the groups to have meaningful input. The WWF standards can be improved by continuing the dialogue process and by the continued provision of stakeholder knowledge.

In summary, we feel that it is good that the WWF has initiated this dialogue. Although we may not wholeheartedly endorse the restricted number of indicators they have selected to measure, clear criteria have been selected. The feeling was fairly unanimous within the groups that the metrics they have chosen are the simplest but that this provides a very truncated view of the interactions between bivalve aquaculture and the environment. Notwithstanding our concerns, it is, after all, up to the WWF and the process they have put in place to identify the criteria to measure. Ultimately, this is their decision based on the dialogue process.

Annex 1: List of participants

Name	Address	Phone/Fax	Email
Chris McKindsey (chair)	Institut Maurice-Lamontagne Fisheries and Oceans Canada PO Box 1000, Mont-Joli, Quebec G5H 3Z4 Canada	+01-418-775-0667 +01-418-775-0752	chris.mckindsey@dfo-mpo.gc.ca
Karin K. Boxaspen	Research and Advice, Aquaculture Institute of Marine Research Bergen, Norway	+47 55 23 85 00 +47 55 23 86 46	karinb@imr.no
Myriam Callier	School of Biology and Environmental Science Science Centre West University College Dublin Belfield, Dublin 4 Ireland	+353 1 716 2013 +353 1 716 1153	myriamcallier@hotmail.com
Matt J. Gubbins	FRS Marine Laboratory 375 Victoria Road Aberdeen, Scotland AB11 9DB	44(0)1224 295681 44(0)1224 295511	m.gubbins@marlab.ac.uk
Thomas Landry	Aquatic Ecosystems Gulf Fisheries Centre Fisheries and Oceans Canada P.O. Box 5030, Moncton, NB E1C 9B6 Canada	+01-506-851-6219 +01-506-851-2079	landryt@dfo-mpo.gc.ca
Francis O'Beirn	Marine Imstitute Rinville, Oranmore, Galway Ireland	+353-91-387250 +353-91-387201	francis.obeirn@marine.ie
Ulfert Focken	Johann Heinrich von Thünen-Institut (vTI) Federal Research Institute for Rural Areas, Forestry and Fisheries Institute of Fisheries Ecology, Branch Ahrensburg, Wulfsdorfer Weg 204 22926 Ahrensburg, Germany	+49 4102-70860-15 +49 4102-70860-10	ulfert.focken@vti.bund.de

Annex 2: WGEIM 2010 Revised Agenda

Agenda (revised) – WGEIM annual meeting

29 March – 2 April, 2010, Marine Institute (host: Francis O'Beirn), Galway, Ireland

(bus to and from Institute from Eyre Square @ 8:30, 18:00 return)

Monday, 29 March, 9:00–18:00

- 9.00-9.30 Housekeeping information from Francis
- 9.30-10.00 Introductory round
- 10.00-10.30 Presentation of 2010 ToRs of WGEIM and WGMASC by chairs
- 10.30-11.00 Coffee/tea break
- 11.00-12.30 Discussion on 2010 ToRs and identification of overlap and subjects of mutual interest (including BAD)
- 12.30-13.30 Lunch
- 13.30-15.30 Discussion on roles of WGEIM and WG MASC within ICES
- 15.30-16.00 Coffee/tea break
- 16.00-17.30 Split up in subgroups dealing with common 2010 ToRs to make agreements on how to proceed during the meeting
- 17.30-18.00 Wrap-up discussion

Tuesday, 30 March, 9:00–18:00

- 9.00-9.10 Presentation of ToR A (review and assessment of sustainability indices for bivalve and fish cage culture) (xxx)
- 9.10-9.20 Presentation of ToR B (fouling hazards and risk management approach) (McKindsey-Landry)
- 9.20-9.30 Presentation of ToR C (IMTA and nutrient cycling) (Robinson)
- 9.30-9.40 Presentation of ToR D (fouling hazards and risk management approach) (McKindsey-Landry)
- 9.40-9.50 Presentation of ToR E (Climate change impacts for fish cage culture) (xxx)
- 9.50-10.00 Presentation of ToR F (updates on finfish feed usage) (xxx)
- 10.10-10-20 Presentation of ToR G (OSPAR request on interactions between marine fish cage farming and wild fish stocks) (Eugene Nixon-McKindsey)
- 10.20-10.30 Presentation of ToRs H&I (Reports to SSGHIE) (Nixon-McKindsey)
- 10.30-11.00 Coffee/tea break
- 11.00-12.30 Initial breakouts to discuss ToRs A, C, G, and others as needed
- 12.30-13.30 Lunch
- 13.30-15.30 Breakouts to continue ToR work
- 15.30-16.00 Coffee/tea break

- 16.00-17.30 Continue breakouts
- 17.30-18.00 Discussion on roles of WGEIM and WGMASC within ICES and wrap-up discussion

Wednesday, 31 March, 9:00–18:00

- 9.00-10.00 Reviews of texts to date
- 10.00-10.30 Breakouts to strategize for ToRs
- 10.30-11.00 Coffee/tea break
- 11.00-12.30 Breakouts for ToRs
- 12.30-13.30 Lunch
- 13.30-15.30 Continuation of breakouts for ToRs
- 15.30-16.00 Coffee/tea break
- 16.00-17.30 Continuation of breakouts for ToRs
- 17.30-18.00 Wrap-up discussion

Thursday, 01 April, 9:00–18:00

- 9.00-10.00 Reviews of texts to date
- 10.00-10.30 Breakouts for ToRs
- 10.30-11.00 Coffee/tea break
- 11.00-12.30 Continuation of breakouts for ToRs
- 12.30-18.00 Lunch and site visit (tba)
- 18.00 (later?) Group dinner in Galway

Friday, 02 April, 9:00–15:00

- 9.00-10.00 Reviews of texts to date
- 10.00-10.30 Completion of ToRs
- 10.30-11.00 Coffee/tea break
- 11.00-13.00 Wrap-up discussion, including defining roles for WGEIM and WGMASC
- 13.30-15.00 Lunch (in Galway)

Annex 3: WGEIM Terms of Reference for the meeting in 2010(modified)

2009/2/SSGHIE08 **The Working Group on Environmental Interactions of Mariculture** (WGEIM), chaired by Chris McKindsey, Canada, will meet in Galway, Ireland, 29 March–2 April 2010 to:

a) evaluate the examples of sustainability indices proposed for mariculture activities and critically evaluate those SI's recommended by WGEIM and other fora;

b) investigate and report on fouling hazards associated with the physical structures used in mariculture with a view to developing integrated pest management strategies;

c) review the outputs of a number of integrated aquaculture (multi-trophic culture systems) projects and address the issue of energy and nutrient cycling associated with IMTA systems and report in 2009;

d) review and report on the use of seed stock quality criteria in mariculture and their applications in term of ecological performance;

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

f) provide an update on fin fish feed usage and constituents from member countries to included in the meeting report in 2009.

g) Effects of mariculture on populations of wild fish (OSPAR request 2010/3). While there is general agreement on the range of potential forms of interaction between farmed and wild stocks, there is much less agreement on the current and future significance of these interactions for wild stocks. OSPAR ask ICES:

- To provide advice on the current state of knowledge on the interaction of finfish mariculture on the condition and wild fish populations (both salmonid and non-salmonid) both at a local and regional scale, including from parasites, escaped fish and the use of fish feed in mariculture. Advice is requested on how the interactions will change as a result of an expansion of mariculture activities.
- OSPAR suggest that this should be addressed through a risk analysis approach, making best use of both quantitative and qualitative methodologies, and that an important aspect of the outcome will be clear identification of the specific aspects of the risk analysis where additional research effort may best be targeted to reduce the uncertainty in the risk analysis.
- This work should be coordinated between WGEIM and WGAGFM through communication between the chairs and correspondence.

h) Report to SSGHIE on potential and current contributions of your EG to the Strategic Initiative on Coastal and Marine Spatial Planning (SICMSP).

i) Report to SSGHIE on your plans to promote cooperation between EGs covering similar scientific issues.

j) Bivalve Aquaculture Dialogue (WWF certification process for best practices)

WGEIM will report by 30 April 2010 for the OSPAR Advice and by 15 May 2010 (via SSGHIE) for the attention of SCICOM and ACOM.

Supporting Information

Priority	The activities of this group are fundamental to the work of the Mariculture Committee. The work is essential to the development and understanding of the effects of man-induced variability and change in relation to the health of the ecosystem. The work of this ICES WG is deemed high priority.
Scientific justification	**ToR a)** The group agreed to progress the work on sustainability indices by conducting intercessional work on developing practical indices for finfish aquaculture. This will be achieved by examining data from existing monitoring programmes in member countries. Lead: Ian Davies, Scotland. **ToR b)** Structure associated with mariculture activities can provide considerable surface area for colonisation of species not typically found in the culture area. This is presumably due to the increased habitat complexity and appropriate substrate for epifuanal organisms. In addition to the potential to provide a pathway for the introduction of an exotic nuisance species to a system, additional problems encountered are those associated with the management of the uisance to reduce the impact on the culture acitivity. This ToR will highlight existing examples and will address the management implications and potential mitigation strategies by examinaning a range of case studies from Canada and Spain specifcially. Lead: Chris McKindsey, Canada. **ToR c)** Evaluation of the outputs of a number of integrated aquaculture (multi-trophic culture systems) projects has been covered by WGEIM for the last number of years and will continue to be evaluated by the group. In addition, the output of nutrients in IMTA or production systems in general, may lead to increased productivity or anoxic systems with consequences at both ends of the spectrum (water column and benthos). In bivalve culture, planktonic communities may be altered directly through grazing with respect to flushing and differential reproduction of plankton communities (e.g. compare copepod reproduction to heterotrophs). Various nutrient fluxes (from bivalves and structures as well as benthos) may impact water column nutrient dynamics and thus the whole pelagic ecosystem. This ToR will examine the fate of energy and nutrients form aquaculture systems and discuss the consequences for the environment and IMTA systems in general. Lead: Stephen Cross and Shawn Robinson, Canada. **ToR d)** For economical reasons, mariculture development is based on the continuous improvement of seed and fry, being wild or produced in hatcheries. How these improvements, particularly those which contribute to increase the physiological fitness and food efficiency may impact the use of the resources from the natural environment is a question of high relevance for decision making. The trade off between the economical and the ecological performance of mariculture, and consequently the regulations (e.g. licensing) to follow, is consistent with the objectives of sustainability and responsible natural resources management. The aim of this work will be to review the use of seed stock quality criteria in mariculture and their applications in term of ecological performance. Lead: Thomas Landry, Canada. **ToR e)** Predicting the impact of climate change on marine systems has become an important and topical exercise for numerous authorities in recent years. Numerous predictions relating to sea level rise and water

	temperature changes have sparked considerable speculation on the potential to influence the distribution of marine species. Aquaculture species, particularly those found on the boundaries of climatic regions, may be at risk of greatest impact due to climate change. The geographical distribution of some highly productive and important aquaculture processes and species could expand as a consequence of a rise in sea temperatures (e.g. range expansion of reproducing populations of Crassostrea gigas to more northerly parts of Europe). Other issues that might be covered are the influene changing climate might have on the prevalence of disease causing organims, the potential to culture new species, influence on harmful algal blooms, the impact of increased run-off might have on shellfish waters classification and the impacts of increased storminess might have on mariculture activities. Lead: no lead assigned yet. **ToR f)** WGEIM and other ICES group have previously reviewed the issue on fin fish feed usage and constituents from member countries. However, the sustainability of utilising fish based feed products for marine fish farm activities continue to be questioned and justification continues to be sought. Feed producing companies are apparently endeavouring to find alternative sources. The goal of this work package is to provide an update within each member country of the proportion and constituents of alternative feeds used in finfish aquaculture. Lead: no lead assigned yet. **ToR g)** This is an OSPAR Request (2010/3). The scale of cultivation of both fish and shellfish species in coastal waters of the OSPAR area continues to increase. In some countries, the value of aquaculture products exceeds that from wild capture fisheries. Aquaculture is currently concentrated in coastal waters. taking advantage of the sheltered conditions available there, and also in response to other practical economic and engineering factors, such as accessibility for operators and to downstream processing facilities, and the difficulty and cost of maintaining structures in open water offshore areas. Some of the environmental interactions of coastal aquaculture operate on very local scales. These include enrichment of the seabed by waste feed and faeces, or the potential toxic effects of used chemicals such as medicines and antifoulants. These generally can be regulated through local licensing and consenting systems. However, other forms of environmental interactions have the potential to have influence over rather larger areas. A number of these concern wild fish populations. Examples include the pressure on wild stocks to provide raw materials (fish protein and lipid) for pelleted diets for farmed fish, interbreeding of escaped farmed fish with wild stocks reducing their fitness, and the more direct stress arising from the possible transfer of parasites of farmed to wild stocks (notably sea lice from farmed salmon to wild salmon and sea trout) and consequent impacts on wild populations. **ToR h)** This strategic initiative is currently being planned and suggestions from EGs on their engagement in the SICMSP are sought. **ToR i)** Collaboration across EGs is encouraged and may be facilitated by e.g. inviting EG chairs and/or key members to attend meetings of your EG, and to use teleconferencing and videoconferencing as means to engage participants remotely. **ToR j)** Standards of best practice for certification for mariculture operations are being developed world-wide. This workshop affords the unique opportunity for both the WGEIM and WGMASC to comment on one such standard, that proposed by the WWF, before it is adopted.
Resource Requirements	None
Participants	The Group is normally attended by some 12–15 members and guests

Secretariat Facilities	None
Financial	No financial implications
Linkages to Advisory Committees	ACOM
Linkages to other committees or groups	WGEIM interacts with WGMASC, WGAGFM, MARC
Linkages to other organisations	The work of this group is undertaken in close collaboration with the DFO Gesamp group, BEQUALM, OIE, EU, EAS, PICES

Annex 4: OSPAR request to develop Risk Assessment for the effects of mariculture on wild fish populations in member nations

ANNEX 21
(Ref. §20.2)

OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic

Meeting of the OSPAR Commission

Brussels (European Commission): 22–26 June 2009

2010 ICES work programme

A. – Scientific Advice

1) Extending marine assessment and monitoring framework used in Chapter 10 of the QSR 2010

To review the methodology used by the OSPAR workshop on the development of Chapter 11 of the QSR 2010 (Utrecht workshop)[2] and taking into account, inter alia, ICES work on integrated assessment and developments in relation to the Marine Strategy Framework Directive, provide advice on the following aspects:

a) improvements that could be made to the thresholds between different assessment classes, including any scientific basis for proposed thresholds;

b) extending the methodology to support the assessment of plankton communities;

c) improving the method for working at different scales, such as the level of an OSPAR Region, the level of sub-Regions such as the Irish Sea or the Channel or the level of an estuary or Marine Protected Areas.

More detailed terms of reference for this request will be provided in January 2010.

2) Monitoring methodologies for ocean acidification

To provide, on the basis of a review of existing methodologies and experience, recommendations for cost efficient methods for monitoring ocean acidification (OA) and its impacts, including possibilities for integrated chemical and biological monitoring. Specifically this should provide:

a) advice on appropriate parameters, protocols and quality assurance for monitoring changes in pH and inorganic carbon chemistry in the OSPAR maritime area and other ancillary parameters that should be included in monitoring programmes;

b) advice on the status of current knowledge on spatial and temporal variability of pH and inorganic carbon chemistry in the OSPAR maritime area;

[2] Although the workshop title referred to Chapter 11, the output has subsequently been reflected in Chapter 10 of the QSR.

c) advice on appropriate spatial and temporal coverage for monitoring, considering different oceanographic features and conditions and key habitats/ecosystems at risk from OA in the OSPAR maritime area;

d) advice on the status and maturity of potential indicators of OA impacts on species, habitats and ecosystems that could be considered for inclusion in OSPAR monitoring programmes.

3) Effects of mariculture on populations of wild fish

Background

The scale of cultivation of both fish and shellfish species in coastal waters of the OSPAR area continues to increase. In some countries, the value of aquaculture products exceeds that from wild capture fisheries. Aquaculture is currently concentrated in coastal waters, taking advantage of the sheltered conditions available there, and also in response to other practical economic and engineering factors, such as accessibility for operators and to downstream processing facilities, and the difficulty and cost of maintaining structures in open water offshore areas.

Some of the environmental interactions of coastal aquaculture operate on very local scales. These include enrichment of the seabed by waste feed and faeces, or the potential toxic effects of used chemicals such as medicines and antifoulants. These generally can be regulated through local licensing and consenting systems.

However, other forms of environmental interactions have the potential to have influence over rather larger areas. A number of these concern wild fish populations. Examples include the pressure on wild stocks to provide raw materials (fish protein and lipid) for pelleted diets for farmed fish, interbreeding of escaped farmed fish with wild stocks reducing their fitness, and the more direct stress arising from the possible transfer of parasites of farmed to wild stocks (notably sea lice from farmed salmon to wild salmon and sea trout) and consequent impacts on wild populations.

Request

While there is general agreement on the range of potential forms of interaction between farmed and wild stocks, there is much less agreement on the current and future significance of these interactions for wild stocks. OSPAR requests ICES to:

To provide advice on the current state of knowledge on the interaction of finfish mariculture and wild fish populations (both salmonid and non-salmonid) both at a local and regional scale, including from parasites, escaped fish and the use of fish feed in mariculture. Advice is requested on how the interactions will change as a result of an expansion of mariculture activities.

OSPAR suggest that this should be addressed through a risk analysis approach, making best use of both quantitative and qualitative methodologies, and that an important aspect of the outcome will be clear identification of the specific aspects of the risk analysis where additional research effort may best be targeted to reduce the uncertainty in the risk analysis.

4) Environmental interactions of wave and tidal energy generation devices (Marine wet renewables)

Background

The utilisation of marine resources of wave and tidal energy for the generation of electricity is a new, but rapidly growing, sector of marine industry. Parts of the OSPAR area are particularly suitable for this type of development. Full or reduced scale devices have been tested at various locations, and the industry is now moving towards planning for the installation of arrays of full scale devices with commercial exploitation in mind.

The industries are by no means mature, and there is considerable diversity in the engineering design of power generators, as well as uncertainty in the predicted interactions of the devices with the marine environment and its ecosystems (habitats and species).

National and international targets for renewable energy production clearly indicate that development will be rapid over the next decade, and will continue beyond then to meet the need for low carbon technologies. The low level of understanding of the environmental interactions of these devices, and of appropriate mitigation measures, may tend to inhibit development, and also limit the degree to which marine spatial planning can contribute to positioning wet renewable energy within a framework of sustainable exploitation of the sea. Potentially significant interactions include those with protected species (e.g. marine mammals, seabirds) and habitats, coastal processes. A clear understanding of these interactions will be an important aspect of licensing of wet renewables developments, and will include assessments against the requirements of the EU Habitats and Species Directive, and Birds Directive, which in turn are linked with the OSPAR Biodiversity Strategy and assessment against OSPAR EcoQOs.

Request

To provide advice on the extent, intensity and duration of direct and indirect effects and interactions of marine wet renewable energy production (wave, tidal stream and tidal barrage systems) with the marine environment and ecosystems of the OSPAR maritime area, and with pre existing users of these ecosystems, including:

a) actual and potential adverse effects on specific species, communities and habitats;
b) actual and potential adverse effects on specific ecological processes;
c) irreversibility or durability of these effects.

5) Impacts of human activities on cold water corals and sponge aggregations

To provide advice on impacts of human activities on cold water corals and deep sea sponge aggregations including:

a) total amounts and % of these habitats affected by human activity over the past decade, on a year by year basis, in the OSPAR maritime area;
b) specific sites within the North-East Atlantic where records show that more than 100 kg of live coral of 1000 kg of live sponges have been trawled as a result of human activities in the past;

c) what is known about the status of coral reefs and sponge aggregations in these areas;

d) recovery rates of these species if and when damaged or removed;

e) possibilities for re-creation of these habitats

6) Atmospheric monitoring of PFOS

To provide advice on whether it is appropriate to include PFOS in atmospheric monitoring programmes and if other perfluorinated compounds should be included in such monitoring to support assessments of inputs of PFOS to the marine environment.

B Data handling

7) Carry out data handling including quality assurance activities for CEMP data

This activity covers the following data types:

a) contaminant concentrations in biota and sediments;

b) measurements of biological effects;

c) arising from the implementation of the Eutrophication Monitoring Programme;

d) data on phytobenthos, zoobenthos and phytoplankton species.

Annex 5: Descriptive mechanisms and qualitative measures of consequences of fish cage farming used in Risk Assessment of the effects of mariculture on wild fish populations in OSPAR countries

Table A. Descriptive mechanisms and qualitative measures of consequences of predation by escaped farmed fish on wild fishes.

Level	Descriptor	Detailed mechanisms
1	Insignificant	Fish known not to feed on fish Fish not expected to survive for extended periods if escaped Escape event is very limited
2	Minor	Fish is a generalist feeder and expected to survive once escaped Fish is piscivorous but not expected to survive for extended periods or else main prey species are of robust populations Escape event of ecologically important species is limited → Limited impacts, changes in fish populations/assemblages in terms of abundances and diversity are detectable but are of short duration (seasonal to year) and small spatial scale (immediate vicinity of farm site)
3	Moderate	Fish is piscivorous and expected to survive once escaped Populations of some prey species may be vulnerable to increased predation Escape event of ecologically important species is moderate → Considerable impacts, changes in fish populations/assemblages in terms of abundances and diversity are moderate and are of moderate (year scale) duration and spatial (bay scale)
4	Major	Fish is piscivorous, expected to survive, main prey species are of vulnerable populations/stocks and are of conservation importance. Escape event of ecologically important species is massive → Great impacts, changes in fish populations/assemblages in terms of abundances and diversity are marked and are of long (multi-year scale or permanent) duration and spatial (coastal scale or greater)

Table B. Descriptive mechanisms and qualitative measures of consequences of competition (for food/habitat) by escaped farmed fish with wild fishes.

Level	Descriptor	Detailed consequences
1	Insignificant	Fish known not to use the same resources (food, habitat) as other fish species Fish is not expected to survive for extended periods if escaped Escape event is very limited → No impact, or changes in fish populations/assemblages not readily detectable or of short duration and small spatial scale
2	Minor	Fish is a generalist in terms of resource use and is expected to survive once escaped Escape event of ecologically important species is limited → Limited impacts, changes in fish populations/assembalges in terms of abundances and diversity are detectable but are of short duration (seasonal to year) and small spatial scale (immediate vicinity of farm site)
3	Moderate	Fish is expected to survive once escaped, is a specialist in terms of resource use and competes directly with other specialist species for resources Escape event of ecologically important species is moderate → Considerable impacts, changes in fish populations/assemblages in terms of abundances and diversity are moderate and are of moderate (year scale) duration and spatial (bay scale)
4	Major	Fish is expected to survive once escaped, is a superior competitor with vulnerable populations/stocks that are of conservation importance. Escape event of ecologically important species is massive → Great impacts, changes in fish populations/assemblages in terms of abundances and diversity are marked and are of long (multi-year scale or permanent) duration and spatial (coastal scale or greater)

Table C. Descriptive mechanisms and qualitative measures of consequences of competition by escaped farmed fish with wild fishes of the same species for food.

Level	Descriptor	Detailed consequences
1	Insignificant	Fish known not to feed on same resources if of farmed origin Fish not expected to survive for extended periods if escaped Escape event is very limited → No impact, or changes in fish populations/assemblages not readily detectable or of short duration and small spatial scale
2	Minor	Fish expected to survive for extended periods if escaped and feed abundant in natural environment and not likely to be limiting Escape event of ecologically important species is limited → Limited impacts, changes in fish populations/assembalges in terms of abundances and diversity are detectable but are of short duration (seasonal to year) and small spatial scale (immediate vicinity of farm site)
3	Moderate	Fish may be specialist and likely to feed on same resources if of farmed origin and likely to survive for extended periods and populations of some prey species are limiting Escape event of ecologically important species is moderate → Considerable impacts, changes in fish populations/assemblages in terms of abundances and diversity are moderate and are of moderate (year scale) duration and spatial (bay scale)
4	Major	Fish is specialist, likely to survive, and prey is limiting. Escape event of ecologically important species is massive → Great impacts, changes in fish populations/assemblages in terms of abundances and diversity are marked and are of long (multi-year scale or permanent) duration and spatial (coastal scale or greater)

Table D. Descriptive mechanisms and qualitative measures of consequences of competition by escaped farmed fish with wild fishes for habitat.

Level	Descriptor	Detailed consequences
1	Insignificant	Fish non-territorial and habitat not limiting Fish not expected to survive for extended periods if escaped Escape event is very limited → No impact, or changes in fish populations/assemblages not readily detectable or of short duration and small spatial scale
2	Minor	Fish is expected to survive for extended periods, is not territorial and habitat is not limiting Escape event of ecologically important species is limited → Limited impacts, changes in fish populations/assembalges in terms of abundances and diversity are detectable but are of short duration (seasonal to year) and small spatial scale (immediate vicinity of farm site)
3	Moderate	Fish is expected to survive for extended periods, is territorial and habitat is not limiting, leading to potential competition for prime territories Escape event of ecologically important species is moderate → Considerable impacts, changes in fish populations/assemblages in terms of abundances and diversity are moderate and are of moderate (year scale) duration and spatial (bay scale)
4	Major	Fish is expected to survive for extended periods, is territorial, dominant. and habitat is limiting Escape event of ecologically important species is massive → Great impacts, changes in fish populations/assemblages in terms of abundances and diversity are marked and are of long (multi-year scale or permanent) duration and spatial (coastal scale or greater)

Table E. Descriptive mechanisms and qualitative measures of consequences of competition by escaped farmed fish with wild fishes for reproduction.

Level	Descriptor	Detailed consequences
1	Insignificant	Fish is a broadcast spawner but is triploid or otherwise modified to be infertile Fish is not expected to survive for extended periods if escaped
2	Minor	Fish is a broadcast spawner and reproductive Fish is a non-broadcast spawner, forms pairs or otherwise exhibits mate selection behaviour, but is infertile or an inferior competitor
3	Moderate	Fish is a non-broadcast spawner, forms pairs or otherwise exhibits mate selection behaviour, but is infertile or an inferior competitor and availability of potential mates is limiting
4	Major	Fish is a non-broadcast spawner, forms pairs or otherwise exhibits mate selection behaviour, is reproductive and a superior competitor and the availability of potential mates is limiting

Annex 6: WGEIM draft terms of reference for the 2011 meeting

The **Working Group on Environmental Interactions of Mariculture** (WGEIM), chaired by Chris McKindsey, Canada, will meet in Charlottetown, Canada, 2–6 May 2011 to:

a) Identify emerging mariculture issues and related science advisory needs to maintain the sustainability of living marine resources and the protection of the marine environment. The task is to briefly highlight new and important issues that may require additional attention by the WGEIM and/or another Expert Group at some time in the future as opposed to providing a comprehensive analysis.

b) Evaluate examples of sustainability indices that take social values into consideration proposed for mariculture activities and critically evaluate those SI's recommended by WGEIM and other fora and report in 2011;

c) Investigate and report on fouling hazards associated with the physical structures used in mariculture with a view to developing integrated pest management strategies;

d) Review the outputs of a number of integrated aquaculture (multi-trophic culture systems) projects and address the issue of energy and nutrient cycling associated with IMTA systems, commercial, legal, and scale issues, and report in 2011;

e) Review and report on the use of seed stock quality criteria in mariculture and their applications in term of ecological performance;

f) Assess the potential impact of climate change on aquaculture activities relevant to each ICES member state;

g) Provide an update on fin fish feed usage and constituents from member countries.

WGEIM will report by 1 June 2011 (via SSGHIE) for the attention of SCICOM.

Supporting Information

Priority	The activities of the WGEIM are fundamental to the work of the SSGHIE and SICMSP. The work is essential to the development and understanding of the effects of man-induced variability and change in relation to the health of the ecosystem. The work of this ICES WG is deemed high priority.
Scientific justification	ToR a) For the WGEIM to be able to address emerging issues and provide the most relevant science advice to promote the sustainable use of living marine resources and the protection of the marine environment, it must first be able to flag emerging issues identified by the various participants. The intention of this activity is to flag issues identified by the group as a whole that may require future attention by the WGEIM or other related ICES Expert Groups, either alone or through collaborative work. The WGEIM chair will cross-reference proposed work with SCICOM and relevant Expert Groups. ToR b) The group agreed to progress the work on sustainability indices by conducting intercessional work on researching and developing practical indices for bivalve and finfish aquaculture. This will be achieved by examining data from existing monitoring programmes in member countries, for example the programme EVADE, in France. ToR c) Structure associated with mariculture activities can provide considerable surface area for colonisation of species not typically found in the culture area. In addition to the potential to provide a pathway for the introduction of an exotic nuisance species to a system, additional problems encountered are those

	associated with the management of the nuisance species to reduce the impact on the culture acitivity. This ToR will highlight existing examples and will address the management implications and potential mitigation strategies by referring to international case studies. ToR d) Evaluation of the outputs of a number of integrated aquaculture (multi-trophic culture systems) projects has been covered by WGEIM in recent years and will continue to be evaluated by the group. In addition, the output of nutrients in IMTA or production systems in general, may lead to increased productivity or anoxic systems with consequences at both ends of the spectrum (water column and benthos). Various nutrient fluxes (from fish, bivalves and structures as well as benthos) may impact water column nutrient dynamics and thus the whole pelagic ecosystem. This ToR will examine the fate of energy and nutrients form aquaculture systems and discuss the consequences for the environment and IMTA systems in general. There are also considerable commercial and legal issues associated with IMTA. For example, when is a site considered to be an "IMTA" site? This simnple question is of importance when granting licenses or permits and for marketing, etc. ToR e) For economic reasons, mariculture development is based on the continuous improvement of seed and fry from wild or hatchery sources. How these improvements, particularly those which contribute to increase the physiological fitness and food efficiency, may impact the use of the resources from the natural environment is a question of high relevance for decision making. The trade off between the economic and the ecological performance of mariculture, and consequently the relevant regulations (e.g. licensing), is consistent with the objectives of sustainability and responsible natural resources management. This work will review the use of seed stock quality criteria in mariculture and their applications in term of ecological performance. ToR f) Predicting the impact of climate change on marine systems has become an important and topical exercise for numerous authorities in recent years. Numerous predictions relating to sea level rise and water temperature changes have sparked considerable speculation on the potential to influence the distribution of marine species. Aquaculture species, particularly those found on the boundaries of climatic regions, may be at risk of greatest impact due to climate change. The geographical distribution of some highly productive and important aquaculture processes and species could expand as a consequence of a rise in sea temperatures (e.g. range expansion of reproducing populations of Crassostrea gigas to more northerly parts of Europe). Other issues that might be covered are the influence changing climate might have on the prevalence of disease causing or other harmful organisms – such as fouling pest species, the potential to culture new species, influence on harmful algal blooms, the impact of increased run-off might have on shellfish waters classification and the impacts of increased storminess might have on mariculture activities. ToR g) WGEIM and other ICES group have previously reviewed the issue on fin fish feed usage and constituents from member countries. However, the sustainability of utilising fish-based feed products for marine fish farm activities continue to be questioned and justification continues to be sought. Feed producing companies are apparently endeavouring to find alternative sources. The goal of this work is to provide an update within each member country of the proportion and constituents of alternative feeds used in finfish aquaculture.
Resource requirements	None
Participants	The Group is normally attended by some 10–12 members and guests.
Secretariat facilities	None.
Financial:	No financial implications.
Linkages to advisory committees	ACOM

Linkages to other committees or groups	The WGEIM interacts with the WGMASC, WGIMTO, and the WGPDMO, and the work is relavant to WGICZM.
Linkages to other organizations:	The work of this group is undertaken in close collaboration with the DFO, GESAMP, BEQUALM, OIE, EU, EAS, PICES

Annex 7: Recommendations

Recommendation	For follow up by:
1. The WGEIM recommends to add ToR a to identify and report on emerging mariculture issues and related science advisory needs for maintaining the sustainability of living marine resources and the protection of the marine environment.	SCICOM
2. The WGEIM recommends that Sci Com send the review on the Bivalve Aquaculture Dialogue that our groups conducted to the appropriate representative at WWF to aid and put ICES input in their dialogue process.	SCICOM
3. The WGEIM suggests that the risk assessment matrix developed be adopted by other Expert Groups (WGAGFM and WGPDMO) to contribute to the OSPAR request to evaluate the risk of fish culture on wild fish populations.	SCICOM WGAGFM WGPDMO
4. The WGEIM suggests that the WGECO contribute to the risk assessment to evaluate the risk of fish culture on wild fish populations with respect to the use of wild fish stocks for the production of aquafeeds.	SCICOM WGECO
5. The WGEIM recommends that ToR b be addressed in detail in 2011. This will include a review of sustainability indices that include socioeconomic aspects as well as biological ones by reviewing international cases.	SCICOM WGEIM
6. The WGEIM recommends that ToR d be addressed in detail in 2011. This will include a review of legal and commercial implications and review international cases.	SCICOM WGEIM
7 The WGEIM recommends that ToRs c, e, f, and g remain active but not be addressed in 2011 so that other ToR may be addressed in more detail.	SCICOM,
8. The WGEIM suggests that the review of the WWF Bivalve Aquaculture Dialogue by both the WGEIM and WGMASC be communicated by SciCom to the appropriate authorities.	SCICOM
9. The WGEIM recommends increasing cooperation with WGMASC through joint meetings every 3 years. In the meantime the chairs of both groups will stay in close contact through teleconferencing and videoconferencing about the ToRs being worked on to see any overlaps. If this is the case they can then invite key members of the respective group to the annual meetings to work on the ToRs together or else address the specific ToR at future joint meetings. In addition, chairs will exchange draft reports immediately after their respective meetings and ask key members of their group to review the text on related ToRs.	SCICOM, WGEIM WGMASC
10. The WGEIM recommends that ICES encourages member states for better participation to EGs dealing with mariculture issues. This is particularly true given the increasingly important role of mariculture in coastal areas throughout all member nations.	SCICOM

Annex 8: Technical Minutes of RGMAR

Request 2010_3 by OSPAR

While there is general agreement on the range of potential forms of interaction between farmed and wild stocks, there is much less agreement on the current and future significance of these interactions for wild stocks.

OSPAR ask ICES:

To provide advice on the current state of knowledge on the interaction of finfish mariculture on the condition and wild fish populations (both salmonid and non-salmonid) both at a local and regional scale, including from parasites, escaped fish and the use of fish feed in mariculture. Advice is requested on how the interactions will change as a result of an expansion of mariculture activities.

OSPAR suggest that this should be addressed through a risk analysis approach, making best use of both quantitative and qualitative methodologies, and that an important aspect of the outcome will be clear identification of the specific aspects of the risk analysis where additional research effort may best be targeted to reduce the uncertainty in the risk analysis.

Four expert groups (WGPDMO, WGEIM, WGAGFM and WGEIM) were asked to work on the OSPAR request during their meetings in 2010. The expert groups have considered:

1) Impacts due to disease transfer, especially with respect to sea lice (covered by WGPDMO);
2) Impacts on wild fish stocks due to their being used as raw material to provide fish oil and protein for fish feed (covered by WGEIM);
3) Impacts due to interbreeding of escapees and escaped gametes and wild fish and gametes; and (covered by WGAGFM);
4) Impacts due to interactions between wild and farmed fish due to competition, and other ecological processes (covered in part by WGNAS, WGEIM).

The reviewers were given very limited time to carry out their review. As a result not all EG reports were reviewed by all reviewers.

Summary of review

Impact:	1. Disease transfer	2. Depletion of stock for feed production	3. Interbreeding	4. Interactions
Technically correct	Yes, for sea lice transfer to wild salmon and sea trout. Does not cover other species or other diseases.	Yes	Yes, but voluntarily skips salmonids literature. The genetic implications are not reviewed.	Yes

Impact:	1. Disease transfer	2. Depletion of stock for feed production	3. Interbreeding	4. Interactions
Scope and depth	Not much detail reported, rather general overviews.	Very good	Good, considering the paucity of specific information on interbreeding of non-salmonids.	Combining both WGNAS and WGEIM, very good. The material in WGNAS is particularly well presented and up to date and so where there is overlap the WGNAS material may be preferred. WGNAS review on means of identifying escaped salmon is very good.
Prediction of change vs mariculture expansion	Yes, for transfer of sea lice vs increased mariculture.	Briefly touched, in the sense that sustainability will be the main factor for those fisheries.	Were not made, although they are obvious and similar to the other impacts.	Yes, greater impact expected
Risk analysis approach	Not done in a useful way	Excellent work, focus was on this approach	Not done	Partial, only discussed, not done systematically
Identification of additional research needed to reduce uncertainty	Yes, but missing some	Missing, but the knowledge review seem to indicate that the uncertainty level regarding this question is low.	Yes – basic research on popn diversity needed to evaluate the potential impact of interbreeding.	Yes, research need identified but not in link to reduction of uncertainty.
Additional research recommended by reviewers	Other diseases and fish species. More information needed on the impact of the sea lice transfer on wild populations. More on sea lice treatment alternatives.		More research on low cost tagging methodologies to trace escaped fish (and origin)	More research to evaluate impact for a river under its reproductive baseline. Development of cage technologies (reducing escape potential)

Detailed Review of reports and their responses

2) Impacts on wild fish stocks due to their being used as raw material to provide fish oil and protein for fish feed (**covered by WGEIM**)

1) Covered in Section 3.3 of WGEIM report. Overall, I find the coverage of current knowledge appropriate, and the risk analysis approach very well done – it's my preferred format. I concur with their conclusion that fishing for forage "consequence has a moderate impact with a likely likelihood(!) with very low uncertainty, yielding an

overall risk of high with very low uncertainty (!). We feel that the same logic may be used with respect to consequences for the environment". In summary, they are rather certain based on the available information that it's likely that fishing for forage has a moderate impact (and more pressure will likely increase this impact).

If they provided recommendations, they got lost in the document (I didn't find them) and should have been provided in a dedicated section.

2) I fully agree with the Table 8 of the WGEIM report assessment that use of fish feed in aquaculture is likely to have a moderate or high impact of fish stocks and also on ecosystems where these pelagics are dominant in the foodweb.

4) Impacts due to interactions between wild and farmed fish due to competition, and other ecological processes (**covered in part by WGNAS, WGEIM**).

1) It seems that WGEIM assumed that the coverage of the ecological aspects of the interaction was done by the WGECO (working group on ecosystem effects of fishing activities).

WGNAS covered the impact of escapees but focused on Atlantic salmon. The coverage of this is very good, data gathering is excellent. Although some information from WGNAS and WGEIM overlap, WGNAS focused on general impacts from salmon escapees (competition for habitat, food, reproduction), but not on the impact of interbreeding, which was well explained by WGEIM but mostly for non salmonids.

2) WGNAS Section 6 deals with the incidence of escapes of farmed salmon. This seems to me to be an excellent review, very well presented and thorough.

The WGEIM report seems to make little or no use of the good work by WGNAS. For example Figure 3 uses the same data as in WGNAS but without the 2009 datum which suggests that older sources are used rather than the up to date WGNAS report.

Table 4 of the WGEIM report is not very good. Ecosystem effects of fishing can include many aspects not listed here, and in the context of small pelagic fish the emphasis on destruction of the seabed by trawling is inappropriate. Some comment on effects of stock depletion on top predator populations would be more relevant.

I like the WGEIM text all the way up to the end of Section 3.3.1. But unfortunately section 3.3.2 is very weak. WGEIM states (end of Section 3.3.2) that it lacked necessary expertise on ecosystem effects of fisheries on small pelagics. Can I suggest that it is essential to insert text to remedy this? I have drafted something along these lines with regard to impacts of fisheries on small pelagic fish on seabird populations, a topic on which there is a considerable literature (see Annex 2).

In addition, it would seem appropriate in Section 3.3.2 to review the current and recent status of the main global pelagic stocks harvested for fish meal production in order to indicate which of these are in good order and which, if any, might sustain any further increase in effort. I believe that many of these are in poor state (e.g. North Sea sandeel, Icelandic capelin, Benguela sardine and anchovy, etc.). I presume ICES has up to date data on this.

3) The document is well organized and reads well. It could perhaps benefit from an upfront executive summary that highlights the results of the risk assessment. One of the weaknesses of the report is that several key areas of risk are considered by other groups. The logic resulting in the assignment of a minor consequence to disease transfer with a low likelihood should be more fully unsubstantiated, particularly given that the report indicates the topic is not well studied, and the WGPDMO rec-

ommends more study is needed. Why conduct more study for a low risk? Hopefully, the various components will be combined into a more complete risk assessment at some point so readers and decision makers looking for advice on the risks associated with escapes can refer, at least initially, to one document.

Conclusion

1) Overall, I think that in general, there is a tendency to remain cautious and on the safe side when providing advices and recommendations, hence the risk assessment approach should be used everywhere when possible, and I favour the approach of the WGEIM format for this purpose.

In both the impacts of escaped fish on interbreeding, ecology and competion, etc, a fundamental point is the ability to identify escaped fish and distinguish them from wild stocks, either using tags or other external signs. This is well covered by WGNAS, but not mentioned by WGEIM or WGAGFM.

2) In the Section headed "Conclusions" of Annex 6 of WGPDMO I think the wording is potentially misleading. The authors have been extremely careful to avoid making any claims that are not strongly and clearly supported by scientific studies, which I applaud. But I don't like the conclusion "With the information available, it is not possible to conclude with confidence that these elevated salmon louse infections have or have not had a measureable effect on the abundance of wild salmon population." This is a correct statement, but it is somewhat misleading. I think it would be equally correct to say "Since we know that salmon lice can kill salmon, it is unlikely that the increased rates of salmon louse infestation of wild fish which have been caused by salmon farming will have no effect on wild populations". I think my statement is perhaps more relevant to the needs of OSPAR than the statement that we can't be certain if there is an impact or not! Maybe you can see a way to finesse the text to incorporate my point here without necessarily removing any of the text of the authors?

3) I don´t know if our mandate makes it possible to give any suggestions how to proceed. Because of the insufficiency of knowledge on disease interactions between mariculture and wild populations of fish, it might, however, be beneficial to include risk analysis professional(s) in the work. They might have conception of the ways to proceed in a situation, where there is quite a limited data basis for risk analysis work.

Annex 1

A few sections were noted where the conclusions and recommendations made are questionable:

Risk analysis:

- Part of the risk lies in cage structure and resistance to storms – this risk can be decreased, so it should be a recommendation.

A few specific editorial comments on the WGEIM document:

p.1 ln 16 insert "to" between "likely" and "continue" so it reads "… likely to continue…"

p.9 ln 29 delete "a" from "One study in a Norway …"

p.10 ln 10 insert "a" into "may disperse over large spatial ….’

p. 10 ln 15 "salon" should be spelled "salmon" in " …. farmed salon lacking …"

p.12 ln 40 "show" should be "shown" and "outcompete" should be "out compete" in "…have

been show to outcompete …"

p. 14 ln 2 delete second "of" in "consequence of this ~~of~~ as minor …"

p. 14 ln 21 delete second "of" in "… we assign a consequence of this ~~of~~ as moderate …"

p. 15 ln 21 insert a period after 2009) and delete the and in "close to the bottom (Meager et al.,

2009). ~~and~~ Wroblewski et al. (1996) showed that "

p.15 ln 22 add d to end of escape so it reads escaped

p.15 ln 27 delete one of the blank lines

p. 16 ln 7 delete the s at the end of "millions" in "million~~s~~ tonnes annual production .."

p. 18 ln 41 delete "also in the "…. Similarly, the current risk assessment ~~also~~ does not …."

p. 19 ln. 4 delete "with low" in "varied between minor to moderate ~~with low~~ and were .."

p.19 ln 4 delete "else" in "were considered to be rare or ~~else~~ likely."

Annex 2

The following text was suggested to be added to Section 3.3.2 of WGEIM.

Several studies have shown that industrial fisheries harvesting large quantities of small pelagic fish can have severe impacts on top predators dependent on these stocks for food. Jahncke *et al*. (2004) concluded that growth of seabird populations off Peru from 1925 to 1955 was likely a response to increased productivity of the Peruvian upwelling system, but that the subsequent drastic decline in seabird abundance (involving the loss of several million seabirds) was due to competition for food with the industrial fishery, which caught about 85% of the anchovies, which otherwise would have been available for the seabirds.

The common guillemot *Uria aalge* population in the Barents Sea, estimated to consume 70,000 tonnes of capelin *Mallotus villosus* per year (Mehlum and Gabrielsen 1995) fared well until 1985 but suffered 90% mortality in winter 1985–1986, when the Barents Sea capelin stock fell from 6 million tonnes in 1980 to 500,000 tonnes in 1985 (Barrett and Krasnov 1996). It is believed that industrial fishing of capelin for fish meal and oil, and complex ecological interactions between stocks of cod *Gadus morhua*, herring *Clupea harengus* and capelin, contributed to this stock collapse (Gjosaeter 1998; Gjosaeter et al. 2009; Pedersen et al. 2009). This instability of the capelin stock also resulted in major impacts on the harp seal *Phoca groenlandica* population, and induced cannibalism among cod (Gjosaeter et al. 2009).

Furness and Tasker (2000) identified ecological features of certain seabird species in the North Sea that make them particularly susceptible to reductions in abundance of small schooling pelagic fish such as those harvested for production of fish meal and oil. They identified black-legged kittiwakes *Rissa tridactyla* as particularly good monitors of ecosystem health. Kittiwakes, terns and Arctic Skuas *Stercorarius parasiticus* have all shown reductions in breeding success with declines in North Sea sandeel *Ammodytes marinus* stocks (Furness 2002). Frederiksen et al. (2004) showed strong effects of sandeel fishing locally on the breeding success of kittiwakes at the Isle of May, independent of other environmental factors related to oceanographic change.

At present, many of the world's industrial fish stocks, are at low levels of abundance and are fully or overfished. To the extent that increasing mariculture will require increasing catches of small pelagic fish for aquafeeds, these ecosystem impacts are likely to become more widespread.

Barrett, R. T., Krasnov, J.V. 1996. Recent responses to changes in fish stocks of prey species by seabirds breeding in the southern Barents Sea. ICES J Mar Sci., 53: 713–722.

Frederiksen, M., Wanless, S., Harris, M. P., Rothery, P., and Wilson, L. J. 2004. The role of industrial fisheries and oceanographic change in the decline of North Sea black-legged kittiwakes. J Appl Ecol, 41: 1129–1139.

Furness, R. W. 2002. Management implications of interactions between fisheries and sandeel-dependent seabirds and seals in the North Sea. ICES J Mar Sci, 59: 261–269.

Furness, R. W., and Tasker, M. L. 2000. Seabird–fishery interactions: quantifying the sensitivity of seabirds to reductions in sandeel abundance, and identification of key areas for sensitive seabirds in the North Sea. Mar Ecol Prog Ser., 202: 253–264.

Gjosaeter, H. 1998. The population biology and exploitation of capelin (*Mallotus villosus*) in the Barents Sea. Sarsia, 83: 453–496.

Gjosaeter, H., Bogstad, B., and Tjelmeland, S. 2009. Ecosystem effects of the three capelin stock collapses in the Barents Sea. Mar Biol Res, 5: 40–53.

Jahncke, J., and Checkley, D. M., and Hunt, G. L. 2004. Trends in carbon flux to seabirds in the Peruvian upwelling system: effects of wind and fisheries on population regulation. Fisheries Oceanogr., 13: 208–223.

Mehlum, F., and Gabrielsen, G. W. 1995. Energy expenditure and food consumption by seabird populations in the Barents Sea region. Ed. by H. R. Skjoldal, C. Hopkins, K. E. Erikstad, and H. P. Leinaas. *In* Ecology of fjords and coastal waters, Elsevier, Amsterdam, pp 457–470.

Pedersen, O. P., Pedersen, T., Tande, K. S., and Slagstad, D. 2009. Integrating spatial and temporal mortality from herring on capelin larvae: a study in the Barents Sea. ICES J Mar Sci., 66: 2183–2194.