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Executive summary

The meeting (Chair: Chris McKindsey) was held on 20–23 March 2012 at the Institute of Oceanology Polish Academy of Sciences, Sopot, Poland, and was attended by 10 participants from 5 countries. It had two objectives (1) to have a joint meeting with the WGMASC to collaborate with the WGMASC to discuss how to revitalize the issue of sustainability in aquaculture (ToR i), and (2) to work on other selected Terms of Reference. At the start of the meeting, a presentation on the SSGHIE`s view of the needs for revitalization of the EGs on aquaculture was given by Erik Olsen. Debate was then initiated on how to best address the perceived issues. This discussion continued throughout the session and was concluded with 3 possible scenarios for management structures: the merging of the WGEIM and WGMASC into a single group with an emphasis on sustainability in aquaculture, the formation of an EG on sustainability in bivalve (or invertebrate) culture and another on the sustainability of finfish culture, or keeping the two groups in their current form. The pros and cons of each option were highlighted but no decision was made as to which option was best suited to meet the needs of adequately addressing sustainability in aquaculture. This is likely greatly due to the fact that both groups have addressed this aspect extensively in past ToRs. Given the extensive time devoted to working on ToR h with the WGMASC and that many of the members were new to the WGEIM, limited time was available to address the other ToRs. The group thus decided to focus efforts on finishing 3 multi-year ToRs and addressing a further one that highlights emerging issues.

It was decided by the group to complete those ToR addressed this year and suggested to drop or revise those ToR not being addressed. A more relevant list of ToR was developed by the group and it is planned that this list may also be updated based on the results of our analysis of country-specific interests and knowledge (see ToR h).

a) Five emerging mariculture issues were identified, including 1) the use of wellboats for bath treatment of sea lice chemotherapeutants, 2) standardizing methodologies for monitoring benthic impacts and improving our understanding of sensitive habitat responses to aquaculture induced stress, 3) Effect of fish cage culture on wild fish quality and behaviour, 4) Interactions between seaducks and bivalve culture, and 5) Issues relating to ocean ranching of invertebrates;

b) All human activities in the marine environment, including aquaculture, have some impact. Indices of sustainability of aquaculture activities must include both biological information and social values. Levels of what are deemed to be acceptable impacts are largely a function of societal values and are best considered within an Integrated Coastal Zone Management (ICZM) framework;

c) Fouling hazards and integrated pest management strategies - Postponed;

d) Integrated multi-trophic aquaculture (IMTA) systems typically aim to 1) decrease the impacts of fed mono-specific culture by co-culturing other extractive species (bioremediation) and 2) to increase overall commercial production of all cultured species. Many studies are underway in temperate countries to determine the efficacy of IMTA operations. Remaining regulatory implications include defining what constitutes an "IMTA" site, the scales over which effects must be evident (e.g., lease-scale vs. coast-scale), and issues related to ranching of invertebrates on the seafloor;

e) Seed stock quality may be defined with respect to maximizing profits due to maximized growth, survival and quality and with respect to its environmental performance (food conversion, oxygen demand, production of nutrients and organic waste). Issues with respect to reproductive outputs have received little attention except with respect to maximizing growth rates. It is suggested that seed quality and environmental performance could be improved by increasing use of hatchery-produced seed, broodstock selection, and genetic improvement;

f) Climate change and aquaculture issues – covered by WGMASC, Postponed;

g) Finfish feed usage and constituents – Postponed;

h) The WGEIM collaborated with the WGMASC to address how to revitalize the issue of sustainability in aquaculture. A three-prong approach was suggested:

   i) develop a list of country-specific priorities with respect to sustainability in aquaculture through the development of a table to be circulated to member nations to gauge their level of concern and knowledge of issues identified by the Egs;

   ii) a table of pros and cons of various management structures was devloped to guide the discussion as to the most logical way to address issues surrounding sustainability in aquaculture; discussion of the various options suggests that the creation of a single group would best address the issues surrounding sustainability in aquaculture (although it was recognized that this will create other issues);

   iii) a note was drafted to send to member countries to solicit requests for science advice within the scope of knowledge of the EG(s)

It is anticipated that requests coming directly from member countries will focus a portion of future ToRs for the EG(s), specifically with respect to the development of risk assessments for issues relating to the sustainability of aquaculture. It also anticipated that some ToRs will remain member-driven to meet individual member's needs.

An initial meeting of the anticipated new EG will be held at the ASC in Bergen in September to establish ToRs for the new EG (based on current WGMASC and WGEIM ToRs and results from the survey of member country interests and needs).

i) Potential collaborations with other EGs – covered in 2010, Postponed.

The next meeting was arranged for 18–22 March 2013, in Palavas, France.

1 Opening of the meeting

The ICES Working Group on Environmental Interactions of Mariculture (WGEIM), chaired by Chris McKindsey (Canada), held its meeting in Sopot, Poland, on 20–23 March 2012 at the Institute of Oceanology Polish Academy of Sciences. The meeting was held at the same location and during the same period as the ICES Working Group on Marine Shellfish Culture (WGMASC) annual meeting. The meeting was opened at 9.00 am Tuesday, 20 March by the host Roman Wenne (member of WGMASC), who gave housekeeping information, and the group was welcomed by Prof. Janusz Pempkowiak, the director of the station. The chairs welcomed the members to the meeting and thanked their respective institutions for allowing time and money to participate. New members from Canada (Corina Busby and Gehan Mabrouk), Norway (Raymond Bannister and Vivian Husa), and France (Myriam Callier) were welcomed.

2 Adoption of the agenda

A primary objective of the meeting was to address concerns of SCICOM and SSGHIE that the WGEIM and WGMASC should develop a plan to better address issues relating to sustainability of aquaculture. A related issue is the recent decline by people working on finfish aquaculture within the WGEIM. A presentation to this effect was presented by Erik Olsen, Chair of the SSGHIE. It was also noted that historic overlap of ToRs in the two working groups remained to some extent, although the WGEIM did not work on these ToRs in 2012. The first day of the meeting was largely devoted to plenary discussions to address the issues identified by ICES. This is reported on in Chapter 7 (ToR h). One subject of mutual interest to the two working groups – seed quality – was identified in plenary and was worked on by members of both groups (Chapter 6, ToR g).

The agenda (Annex 2) was modified slightly to accommodate the prolonged discussions on ToR h and these changes are reflected in the revised agenda. A general discussion on plans for each WGEIM ToR was held and it was decided to concentrate on and complete a reduced number of ToRs, to not work further on the remaining ones, and to develop new ones based on the interests of the current EG and their countries and on a plan to identify pressing concerns and abilities (see ToR h). 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, were to reported daily in plenary on work progress. Plans to review work on an ongoing fashion were not fulfilled as time was largely devoted to discussing ToR h). Most ToRs were completed in the first couple of weeks following the meeting and reviewed and commented upon via correspondence through the sub-group leads.

3 Identify emerging mariculture issues and related science advisory needs to maintain the sustainability of living marine resources and the protection of the marine environment (ToR a)

Emerging Issue 1: Use of wellboats for bath treatment of sea lice chemotherapeutants

In the last few years aquaculture operators have started to use wellboats (primarily used for transport and harvest of salmon) as a vehicle for administration of sea lice bath treatments (compounds cypermethrin, deltamethrin, azamethiphos and hydrogen peroxide in Scotland).

The move to wellboats has a number of husbandry and efficacy advantages over more traditional techniques such as the use of tarpaulins (full enclosure or skirts) around cages to provide semi-closed containment, reduced cage volume and temporary increased stocking density. These include more effective use of limited quantities of medicines. In Scotland quantities of bath treatments (except hydrogen peroxide) are conditioned to maximum permitted quantities to avoid breaches of EQS values in the receiving environment. This limitation is restricting the industry's ability to treat sea lice effectively at current production levels for some sites. Therefore the industry is moving to wellboat applications to use limited treatments more effectively (reduced volume in wellboats means reduced treatment quantity). The industry is also currently seeking more licences for discharges of chemotherapeutants from wellboats at new sites remote from aquaculture sites which would provide increased treatment capacity and reduce the risk of re-infection of the treated fish.

There are some environmental risks associated with this new industry activity, primarily the potential for discharge of viable lice and eggs after treatment. (Following treatment and the removal of fish, the remaining water containing active compound, dead (?) lice, egg strings and detritus from fish scales, mucous, etc., is pumped overboard.) In Scotland, use of wellboats is regulated under a Marine Licence (ML) the conditions of which require discharges to be made at the site of fish treatment. This condition is to avoid the potential for dispersion of potentially viable infective lice to sensitive areas for wild salmonids (the risks of which have not been assessed, unlike the location of the fish farm itself).

Currently, no filtration of discharge is implemented by the industry in Scotland and the industry is resistant to implement the approach due to technological difficulties. Should filtration for lice and potentially residual active agents be implemented, then it would enable discharges at remote locations to be undertaken and potentially increase the licensed quantities of treatments and therefore treatment capacity.

Guidance on assessment of the risks associated with discharges from mobile wellboats and cost effective solutions to reduce the discharged quantities of lice or treatments to the marine environment would be of great benefit to regulators and industry alike and may result in a significant increase in effectiveness of sea lice treatments in Scotland.

Emerging Issue 2: Standardizing methodologies for monitoring benthic impacts and improving our understanding of sensitive habitat responses to aquaculture-induced stress

Standardizing methodologies for monitoring benthic impacts

Development and establishment of monitoring methodology/tools for detecting/evaluating environmental impacts of aquaculture to marine ecosystems has been a topic of considerable interest for traditional cultivation locations (i.e., soft sediment habitats) over the past two decades. However, the gradual relocation of aquaculture facilities to deeper localities dominated by hard and mixed substrate habitats has resulted in problems with using these established monitoring tools. Therefore, there is an urgent need to establish standardized monitoring methodology/tools for new habitats (i.e. hard bottom and/or mixed bottom habitats) being exploited through aquaculture operations to improve sustainability.

Sensitive habitat responses to aquaculture induced stress

Over the past decade, there has been an emerging awareness and identification of numerous sensitive habitats/species (i.e. Maerl beds, coral reefs, eel grasses, sponge gardens, breeding/spawning grounds, etc.) in the marine ecosystem, which have important ecosystem functions. This increase in knowledge has resulted in the establishment and identification of these sensitive habitats/species as high conservation value by the Habitats Directive (92/43/EC) established in EU member states. With increasing aquaculture operations and siting of new farms there is increasing concern over the impacts of aquaculture to these sensitive habitats/species. However, there is a lack of scientific based knowledge quantifying the interactions of aquaculture activities and these sensitive habitats/species of high conservation value. Therefore, in the absence of such scientific-based information, applying traditional risk assessments /analysis frameworks is difficult.

Emerging Issue 3: What effect/interaction can marine fish farms have on wild pelagic and demersal fish in a given area?

It is claimed that the presence of marine fish farms affect the wild fish in a given area. Even though the literature on the subject is scarce, both the potential to attract and repel wild fish have been suggested but how they might modify the movement patterns of wild fish species is largely unknown. Farms are for some areas also claimed to have a direct negative effect on the commercial coastal fisheries both in terms of the quality and quantity of the fish. Suspected interactions include general environmental considerations and effects on non-commercial species. Other questions asked include; do effects differ with the species of fish farmed, how do effects vary between species of wild fish and does the effect vary between the different life stages of the fish, such as young fish versus spawning fish.

Pelagic fish

Do farms attract? Dempster *et al*. (2009) the total abundance of wild fish was 20 times greater at four monitored salmon farms compared to a 200 m sampling distance, clearly indicating an attracting effect. Saithe (*Pollachius virens*) dominated assemblages at all farms and were consistently significantly more abundant at the farm than at the 25–200 m distances. This corresponds with older findings concluding that saithe are one of the most common fish species found around fish farms in northern Europe, where they consume surplus feed (Carss 1990; Bjordal & Johnstone 1993). One of the results of this is described by Otterå *et al.* (2009) as giving both higher hepatosomatic and liver indices in the wild fish close to the farms (for other possible effects of feed, see below)

Do farms repell? In several areas along the Norwegian coast local fishermen claim that wild migrating Atlantic cod (*Gadus morhua* L.) have changed their spawning migratory behaviour following establishment of salmon farms, and no longer enter their natural spawning grounds in the fjords. Bjørn *et al*. (2009) blocked the olfactory sense of half the population studied and found that there were no differences in the spatio-temporal distribution cod with intact and cod with blocked olfactory sense. What a possible repellent effect might have on the spawning behaviour and the actual position of the spawning ground is not known.

Farm effect on demersal fish? Negative effects on demersal fish have not been reported. In contrast, Mente *et al.* (2008) found that controlling for differences between individual lochs, proximity to aquaculture facilities did not consistently affect the diet composition of the demersal fish studied, such as haddock. No specific pattern of aggregation was evident for haddock in Dempster's study (op. cit). However, impacts of aquaculture on benthic biodiversity could have cascading effects on the diets of demersal fish and their subsequent success.

Wild fish eating feed from farms: The feed given to salmon will include more fat than the white wild fish natural diet. This might impact filet quality and taste. Otterå *et al*. 2009 found that the diet clearly influenced the growth rate of the fish and found that there were some differences in skin and muscle colour, pH, and in sensory parameters between wild caught and artificially fed saithe at the end of the experiment

Possible areas to be addressed:

- What is the effect on wild fish when attracted away from their natural habitat?
- Can fish farms repel fish from their natural spawning grounds and what effect will this have for the general spawning success and what is the subsequent effect of possible change of geographical location of the spawning ground?
- What biological and commercial effects do the change in fish filet quality due to digestion of too fat feed pellets or introducing a richer diet than natural.
- Feed can possibly contain residues from chemical treatment such as antibiotics and sea lice treatments. What are the risks for human consumption?

Literature most used with abstracts

Bjørn *et al.* 2009. Spatiotemporal distribution of Atlantic cod (*Gadus morhua* L.) with intact and blocked olfactory sense during the spawning season in a Norwegian fjord with intensive salmon farming. Aquaculture. 286, 36-44.

In several areas along the Norwegian coast local fishermen claim that wild migrating Atlantic cod (*Gadus morhua* L.) have changed their spawning migratory behaviour following establishment of salmon farms, and no longer enter their natural spawning grounds in the fjords. This has created a heated debate in Norway and, in some areas, passed down a moratorium on establishing new salmon farms. Research has so far not been able to show a causal connection, but it has been suggested that water-soluble odorants from high density salmon stocks in commercial fish farms might be responsible for the avoidance of areas with fish farming and abandonment of nearby traditional spawning grounds. The aim of this study was to test this hypothesis by studying the spatiotemporal distribution of wild migrating cod tagged with acoustic transmitters using an array of automatic listening stations in Øksfjord, a Norwegian fjord with intensive fish farming and traditional spawning grounds for cod. The tagged cod were released either in the outer parts of Øksfjord, i.e. in the area they were caught, or in the inner part of the fjord close to their traditional spawning areas. The olfactory sense was physically blocked for 50% of the fish. Only one cod released in the outer part of the fjord visited the traditional spawning grounds. The majority of the cod that were released in the inner part of the fjord remained in this area for approximately three weeks before they left the fjord.

There were no differences in spatiotemporal distribution between cod with intact and cod with blocked olfactory sense. Thus, the results provided no evidence that migrating wild cod avoid areas with fish farming as a response to odorants, but the results do not per se contradict the fishermen's observation that coastal cod have changed their migratory pattern in this fjord.

Mente *et al.* 2008. Diet of demersal fish species in relation to aquaculture development in Scottish sea lochs. Aquaculture. 277, 263-274.

The diets of demersal fish, principally haddock (*Melanogrammus aeglefinus*), whiting (Merlangius merlangus) and several flatfish species, sampled from four Scottish sea lochs (Hourn, Kishorn, Duich and Nevis) which support aquaculture sites, were examined in order to determine whether the impact of aquaculture on benthic biodiversity would affect the diets of demersal fish. Loch Kishorn had the highest maximum planned aquaculture production, loch Nevis follows and lochs Hourn and Duich have the lowest planned production. Samples were collected from locations less than and more than 2000 m from fish farm cages. Fish close to the fish farm cages were on average of greater individual weight than those further away from fish farms. Haddock ate predominantly Malacostracan crustacea, Ophiurid echinoderms and Polychaete annelids; whiting ate predominantly Malacostracan crustacea and teleost fish and flatfish ate Malacostracan crustacea, Polychaete annelids and Ophiurid echinoderms. A small number of saithe sampled had eaten mainly fish farm pellets. Dietary variation in each species was analysed in relation to loch, proximity to aquaculture facilities and fish size. Diet of whiting varied with body size. Dietary differences were observed between the lochs and between sites close to and far from farms in two lochs although these differences cannot be specifically attributed to aquaculture development. Controlling for differences between individual lochs, proximity to aquaculture facilities did not consistently affect diet composition.

Uglem *et al.* 2009. High connectivity of salmon farms revealed by aggregation, residence and repeated movements of wild fish among farms. Mar. Ecol. Prog. Ser. 384, 251-260.

Marine fish farms are widespread in coastal waters throughout the world, yet how they modify the movement patterns of wild fish species is largely unknown. We determined the spatio-temporal distribution of saithe *Pollachius virens* in a fjord system with intensive salmon cage aquaculture in Norway. Abundances of 8000 to 18 000 saithe were estimated around 2 salmon farms in the fjord using an underwater video system. Residence of saithe around fish farms and movements among farms and throughout the fjord were studied using implanted acoustic transmitters and an extensive array of automatic receivers. Of the saithe equipped with acoustic tags, 63% were observed daily at one or more of the 3 farms in the fjord over a 3 mo period. When resident at a farm, saithe spent 8 to 10 h d(-1) close to the sea-cages. Periods of residence at specific farms were interspersed with rapid and frequent movements to adjacent farms 1.6 to 4.7 km away. Of 24 tagged saithe, 15 moved among farms 2 to 21 times during the 3 mo period. If the movement patterns of the tagged fish are representative of the movements of untagged saithe, we estimate that fish from 2 different farms resulted in a total (+/- SE) of 167 112 +/- 41764 and 7768 +/- 1831 inter-farm movements during the 3 mo period. Thus, fish farms should be considered as connected, not only through ocean currents, but also through wild fish movements. If saithe share pathogens with farmed salmonids, their behaviours imply that they have the potential to act as vectors for diseases and parasites among salmon farms.

Otterå *et al.* 2009. Quality of wild-captured saithe (*Pollachius virens* L.) fed formulated diets for 8 months. Aquac. Res. 40, 1310-1319.

Fish farms may attract wild fish that feed on waste feed from the cages. Saithe, *Pollachius virens* L., are particularly numerous around salmon cages in northern Europe and may obtain a significant proportion of their diet from waste feed. It has been claimed that these fish are of inferior quality to saithe that feed on natural diets; differences are said to include soft muscle tissue and a different taste. In order to document such changes in quality we performed a feeding experiment. Young wild saithe were collected and fed either a lipid-rich salmon diet or a lean cod diet for 8 months. All fish were individually tagged and growth was monitored throughout the experiment. Parameters related to flesh quality were measured. Diet clearly influenced the growth rate of the fish, and many fish reached a very high hepatosomatic index when fed on a salmon diet. However, many fish had a low feed intake and thus a low rate of growth. There were some differences in skin and muscle colour, pH and in sensory parameters between wild caught and artificially fed saithe at the end of the experiment. Those fed the cod diet were more similar to wild saithe than those fed the salmon diet.

Dempster *et al.* 2011. Proxy measures of fitness suggest coastal fish farms can act as population sources and not ecological traps for wild gadoid fish. PLoS Biol. 6, e15646.

Ecological traps form when artificial structures are added to natural habitats and induce mismatches between habitat preferences and fitness consequences. Their existence in terrestrial systems has been documented, yet little evidence suggests they occur in marine environments. Coastal fish farms are widespread artificial structures in coastal ecosystems and are highly attractive to wild fish.

Methodology/Principal Findings

To investigate if coastal salmon farms act as ecological traps for wild Atlantic cod (*Gadus morhua*) and saithe (*Pollachius virens*), we compared proxy measures of fitness between farm-associated fish and control fish caught distant from farms in nine locations throughout coastal Norway, the largest coastal fish farming industry in the world. Farms modified wild fish diets in both quality and quantity, thereby providing farm-associated wild fish with a strong trophic subsidy. This translated to greater somatic (saithe: 1.06–1.12 times; cod: 1.06–1.11 times) and liver condition indices (saithe: 1.4–1.8 times; cod: 2.0–2.8 times) than control fish caught distant from farms. Parasite loads of farm-associated wild fish were modified from control fish, with increased external and decreased internal parasites, however the strong effect of the trophic subsidy overrode any effects of altered loads upon condition.

Dempster *et al.* 2009. Species-specific patterns of aggregation of wild fish around fish farms. Estuar, Coast. Shelf Sci. 86, 271–275.

Fish-farming structures are widespread in coastal waters and are highly attractive to wild fish. Several studies have estimated that tons to tens of tons of wild fish aggregate around fish farms. These estimates assumed that the majority of wild fish are concentrated immediately beneath farms, although this assumption has never been explicitly tested. We tested the hypothesis that abundances of wild fish would be greatest immediately beneath farms and progressively diminish with distance at 4 full-scale coastal salmon (*Salmo salar*) farms in Norway. At each farm, fish were counted with a video-camera system at 5 different distances from the cages (farm 0 m, 25, 50, 100 and 200 m) throughout the water column on three separate days. Combined across all locations and times, the total abundance of wild fish was 20 times greater at the farm than at the 200 m sampling distance. Saithe (*Pollachius virens*) dominated assemblages at all 4 farms and were consistently significantly more abundant at the farm than at the 25–200 m distances. This 'tight aggregation' around farms corresponds to the reliance of saithe on waste feed when they school near farms. In contrast, patterns of distribution of both cod (*Gadus morhua*) and poor cod (*Trisopterus minutus*) varied among farms, with either highest abundances at the farm or a more even distribution of abundance across all 5 distances sampled. No specific pattern of aggregation was evident for the bottom-dwelling haddock (*Melanogrammus aeglefinus*). Our results suggest that the present 100 m no-fishing zone around salmon farms protects the greatest proportion of farm-aggregated saithe and cod from fishing during the daytime. However, whether this reduces their overall susceptibility to fishing requires further research regarding nighttime distribution and movements.

Fernandes-Jover *et al.* 2011. Waste feed from coastal fish farms: A trophic subsidy with compositional side-effects for wild gadoids. Estuar, Coast. Shelf Sci. 91, 559-568.

Aquaculture of carnivorous fish species in sea-cages typically uses artificial feeds, with a proportion of these feeds lost to the surrounding environment. This lost resource may provide a trophic subsidy to wild fish in the vicinity of fish farms, yet the physiological consequences of the consumption of waste feed by wild fish remain unclear. In two regions in Norway with intensive aquaculture, we tested whether wild saithe (*Pollachius virens*) and Atlantic cod (*Gadus morhua*) associated with fish farms (Fassoc), where waste feed is readily available, had modified diets, condition and fatty acid (FA) compositions in their muscle and liver tissues compared to fish unassociated (UA) with farms. Stomach content analyses revealed that both cod and saithe consumed waste feed in the vicinity of farms (6e96% of their diet was composed of food pellets). This translated into elevated body and liver condition compared to fish caught distant from farms for cod at both locations and elevated body condition for saithe at one of the locations. As a consequence of a modified diet, we detected significantly increased concentrations of terrestrial derived fatty acids (FAs) such as linoleic (18:2u6) and oleic (18:1u9) acids and decreased concentrations of DHA (22:6u3) in the muscle and/or liver of Fassoc cod and saithe when compared with UA fish. In addition, the u3:u6 ratio clearly differed between Fassoc and UA fish. Linear discriminant analysis (LDA) correctly classified 97% of fish into Fassoc or UA origin for both cod and saithe based on the FA composition of liver tissues, and 89% of cod and 86% of saithe into Fassoc or UA origin based on the FA composition of muscle. Thus, LDA appears a useful tool for detecting the influence of fish farms on the FA composition of wild fish. Ready availability of waste feed with high protein and fat content provides a clear trophic subsidy to wild fish in coastal waters, yet whether the accompanying side-effect of altered fatty acid compositions affects physiological performance or reproductive potential requires further research.

Emerging Issue 4: Interactions between seaducks and bivalve culture

Predation from diving ducks represents an increasing challenge to the global production of marine bivalves in aquaculture. Growers from Scandinavia, northern Europe and Canada face increasing challenges as (largely) migrating populations of waterfowl have been increasingly impacting their production, often resulting in complete loss of their stock. Caldow *et al.* (2004) report that birds such as oyster catchers consumed 242 tonnes of mussels with a value of £133 000 (19% of total landings) at Menai Strait, UK, in one winter. In the Dutch Wadden Sea, eiders and oyster catchers alone consume 21.8 million kg (fresh meat) of mussels and cockles yearly, much of it from cultured sites (see review in Dankers and Zuidema 1995). In Nova Scotia, a flock of scoters was reported to have taken 75% of the mussels in a mussel farm (Day 1995) and diving ducks may threaten the viability of some farm operations in Prince Edward Island (Thompson and Gillis 2001). These potentially recurring losses require cost effective solutions. In other cases, predation may be a benefit to farmers as waterfowl may remove fouling organisms from stock. In addition, the ecological impacts of this predation on the environment are unknown.

Bivalve farms provide an artificial feeding ground that attracts diving ducks, like common eiders (*Somateria mollissima*), scoters (*Melanitta* spp.), long-tailed duck (*Clangula hyemalis*), goldeneyes (*Bucephala* spp.), and scaup (*Aythya* spp.) as well as various larger waterfowl such as geese and swans as they provide easily accessible food to the birds. Mussel farms in areas in eastern Canada and Norway have recently been increasingly targeted by diving ducks which, once they find an area, often shift their migratory patterns to return to areas to profit from this easily available and high quality food source. Dunthorn (1971) and Davenport *et al.* (2003) suggest that mussels being grown have traits that make them particularly appealing to diving ducks, namely high meat content and thin shells. Indeed, Bustnes (1998) has shown that eiders discriminate and select mussels with these same characteristics. In western North America, predation on infaunal clam culture is so severe that entire foreshore areas have been covered by netting to reduce predation on crops. Attempts to reduce predation in suspended bivalve culture are limited to bird scaring devices, but birds become habituated to these methods rapidly and some evidence has suggested that such systems may actually attract ducks in some areas. In other areas, the abundance of wading birds may also be increased as the birds take advantage of farmed bivalves or the organisms associated with them (Caldow *et al.* 2003). With respect to suspended mussel culture, most successful alternative is physically excluding ducks by installing nets around farms (Ross and Furness 2000). However, applied research is needed to validate solutions as current knowledge on mesh size, colour, material properties, and effective depth with respect to bird diving behaviour lacks scientific validation. In addition, growers who install nets cannot avoid entanglement of fish and diving ducks, and thus create conflict with conservation and fishery regulators.

With respect to suspended mussel culture, studies show that a greater proportion of mussels are lost to the bottom than are consumed by diving ducks, which will select for the ideal mussel size. This represents a potentially greater input of organic material to the bottom than that produced by mussel biodeposition and the consequences of this to the bottom are unknown.

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Emerging Issue 5: Issues relating to ocean ranching of invertebrates

The use of economically valuable macroinvertebrates such as sea urchins or sea cucumbers, as the benthic component of an IMTA system, is attracting considerable industry interest. However, use of containment structures have been shown to be cost-prohibitive beyond that of juvenile rearing. The most efficient production approach for these animals, in terms of growout, is to deploy the juveniles over the seafloor, allowing them to have free range and to consume the organic waste stream (and deposits) not only from fish but from the extractive shellfish component of an IMTA system. The outstanding issues with the ocean ranching of these echinoderms include interactions with wild stocks (and fisheries), the potential impacts (displacement?) of existing habitat, and the required ranching densities needed to offset the waste fluxes.

4 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 (ToR b)

The management of aquaculture activities in marine systems is dependent upon a number of broad principles. These principles will govern the level of intervention required to ensure that activities are managed in manner that is considered sustainable. To this end, the definition of sustainable is fluid and will be dependent on the extent of the activity in question and other activities acting synergistically or antagonistically. Other factors governing the sustainability of an activity are the sensitivity of the receiving environment and the levels of interaction (impact) that are deemed acceptable. These broad principles required to determine the sustainable level of an activity are governed by the following assumptions:

1) All activities carried out in the marine environment will impact on the system in some fashion;
2) These impacts can be measured at some scale be it global, regional and local;
3) The determination of ecological thresholds relating to impact can be informed by scientific investigation; and
4) Ultimately the level of impact permitted is a policy decision made by managers and informed by societal values.

In the last decade, much research has been undertaken to identify a range of applicable indicators that measure, at some level, the interaction between specific aquaculture activities and features of the marine environment. These features can be of a biological, geochemical or broader (visual) nature. Indicators can be measured over a range of scales and have evolved from the presentation of purely impact indicators (e.g. ECASA) to composite indicators (e.g. Life Cycle Analysis - Aubin *et al.* 2006) to more far-reaching indicators of system health (e.g. EU Framework Programs). Framework programmes are used as programmes of assessing broad system health using indicators sensitive to a range of pressures, e.g. WFD, MSFD. These programmes are used to determine overall health in systems that incorporate, among other things, aquaculture activities. In the event of monitoring identifying a failure to meet appropriate standards, targeted (investigative) monitoring can be used to identify the offending activity.

The establishment of thresholds relating to specific indicators is an important consideration when determining the sustainability of activities in areas. A threshold will identify the level of activities that can take place in a system and in many instances will be based upon the ecological tolerance of the system to perturbations. In order to determine the ecological threshold of activities, a good understanding of a range of ecological components is required. Aspects such as sensitivity, resilience, and recoverability should be considered and quantified in some fashion. In other words, it is important that impact indicators have some capacity to measure habitat resilience and recoverability. For example, a point might be reached when disturbance on the system, referred to as a 'tipping point', where the resilience is exceeded and the system reorganizes (Crowder and Norse 2008), compromising ecosystem functioning and consequently ecosystem services. This tipping point must be avoided and a threshold incorporating some precautionary element must be identified well within the boundaries of the 'tipping points' (Figure 4.1). Together with scenario building, ecosystem modelling provides a mechanism to explore resilience and tipping points in habitats and ecosystems.

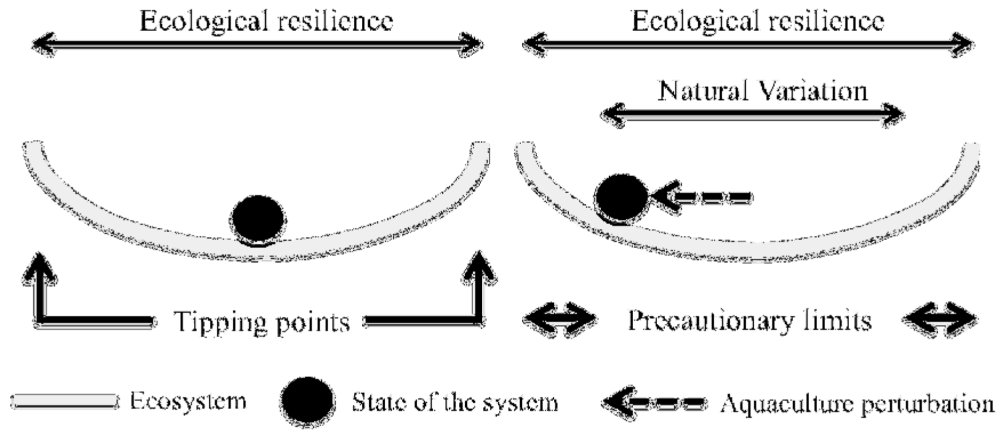

Figure 4.1. The notion of tipping points in ecosystems is a function of the resilience of the system and the extent of the pressure applied.

McKindsey *et al.* (2006) identified four classes of carrying capacity related to shellfish culture activities, i.e. physical, production ecological and social. The first three are broadly quantifiable in some form or another and informed by scientific investigations (including modelling) and research. These categories of carrying capacity can likely be presented in a hierarchical fashion in terms of how much activity will be allowable in a system; for example, while physical capacity may exceed production capacity, both will likely result in a level of activity that would far exceed that which would equate to ecological carrying capacity. However, the extent to which aquaculture activities are allowed in a system will ultimately be governed by the social carrying capacity. Socio-economic considerations will inform management and political policy. Ultimately, the level of environmental/ecological change deemed acceptable in a system as a consequence of a specific (or combination) of activities is governed primarily by social and/or economic views (but see earlier comments on ecological 'tipping points'). This concept has been applied in a number of scenarios whereby the overall extent of aquaculture activities in a system is governed by the process employing strong communication and stakeholder input (Byron *et al.* 2011).

Life cycle assessment (LCA) conducts broad assessments of activities in systems. LCA is a standardized method which comprises a series of environmental impact indicators (including the potentials for eutrophication, acidification and climate change, utilization of the primary product and energy use). The originality of this LCA method is to integrate impacts associated with all the stages of a product's life (i.e. from seed/ hatcheries through growing stage, distribution, disposal or recycling). While the focus is on a single activity, the application of LCA to aquaculture is novel in that it considers the full gamut of likely interactions over a full production cycle.

A challenge to define the sustainability of a production system, as identified in Byron *et al.* (2011), is how to incorporate socio-economic considerations into conventional environmental management systems in a holistic way (ICES 2009). It must be noted that the WGEIM have consistently highlighted the need for socio-economic input to sustainability issue in order to provide a comprehensive commentary of aquaculture sustainability and are summarised below and in Table 4.1.

EVAD approach (Evaluation of the sustainability of aquaculture production systems) is a co-construction approach to build appropriate and applicable indicators. According to this method, sustainability should be defined collectively and not simply by setting a monitoring system. The indicators, in order to be used, must make sense to the stakeholders. The EVAD guide gives practical recommendations on implementation methods and a generic foundation of principles, criteria and indicators established from a wide variety of aquaculture systems. It is a participatory approach, which bring actors together. Based on a selection process of indicators that are linked to the actor's issues and representation and will depend on farm, local, national and regional level (Rey-Valette *et al.* 2008, InDAM project).

The Working Group on Sustainable of Aquaculture (WGSA) of the General Fisheries commission for the Mediterranean, Committee on Aquaculture (CAQ-GFCM) have applied the EVAD approach during the InDAM project (Indicators for Sustainable Development of Aquaculture and Guideline for their used in the Mediterranean) in various Mediterranean countries. The approach is to define a set of indicators related to economic, environmental, social and governance dimensions which are discussed during focus group meetings.

The objective of on-going work (PISCENLIT project) is to define the conditions for ecological intensification of aquatic production systems so as to furnish more products while improving the use of mechanisms of aquatic ecosystem ecology. These conditions are determined not only by the production function but also by other ecosystem services provided by the territories which depend on acceptability and stakeholder perceptions (http://www.piscenlit.org/piscenlit_eng/Presentation)

The broad and inclusive approach adopted under EVAD and subsequent initiatives is a positive step forward in the application of indicators to management activities (aquaculture) in marine systems. Central to these initiatives is a strand relating to communication among stakeholder groups (Byron *et al.* 2011). Clear and open lines of communication among stakeholders (e.g. general public, ENGO, operators, regulators) are critical to effective management strategies in marine systems and acceptance of management strategies implemented.

Table 1. Example of recent project proposing indicators at various scales.

Project	Levels	Objective - Results
EVAD Guide to the co-construction of sustainable development indicators in aquaculture	-Productive system -Regulatory system -Region	Principle-Criteria-Indicator (PCI) method Postulate An indicator is not just a measuring tool As implementing sustainable development is an innovative process, it is based on organisational learning and a specific joint approach The joint approach to building indicators promotes organisational learning and helps dialogue The co-construction approach is an opportunity and often generates organisational innovation
InDAM Indicators for Sustainable Development of Aquaculture and Guideline for their used in the Mediterranean (http://www.faosipam.org/?pag=content/_ShowPortal&Portal=INDAM).	-Farm -Local -National -Regional	Use EVAD approach Based on the production of sets of indicators and relative reference points and standards to guide evaluate Provide incentives towards the sustainable development of Mediterranean aquaculture in its four dimensions (social, economic, environmental and governance) and within an ecosystem based framework.
Mediterrane-ON http://www.mediterraneon.es/	-Farm/business -National -Mediterranean	Application of the Principle-Criteria-Indicator (PCI) method 'SMART' criteria were used in defining the indicators - i.e. being Specific, Measurable, Achievable, Relevant and Time Bound. • Impact: Interaction • Principle: The highest level objective which the impact is directed towards • Criterion: The area that the impact is focused on • Indicator: Measures the extent of the impact To ensure the correct definition and identification of the indicators the following three levels were established: farms and/or production companies, countries and Mediterranean region

The notion of acceptability is critical to fully determine the sustainability of an activity in the marine environment. The term “acceptable”, is governed primarily by social values, starting from a global to local perspectives. The social carrying capacity of aquaculture should be the basis of a sustainability program to assess the sum of activities, such as aquaculture, within a defined area. The principles of these programs could flow from global vision, with regionally based criteria. For example, no net lost or biodiversity may be a global vision. The philosophy underpinning the EU Framework Programmes broadly reflects this call for a global vision and is supported by a strong monitoring and regulatory oversight on a system-wide basis.

Considering the goal of ensuring sustainable levels of activities in the marine environment, the application of Integrated Coastal Zone Management (ICZM) is likely to be an important tool towards achieving this objective. As already highlighted, the importance of linking social, economic and environmental aspects into the management of marine systems is critical as is the need to have broad sectoral cooperation and input into the development of these practices.

ICZM facilitates a shift from management and regulation of activities in the marine environment in isolation to a system where all activities can be considered and resource use is optimised with a view to maintaining the health and productivity of coastal ecosystems so that they can continue to supply resources that sustain different forms of activities, including mariculture. While these goals are lofty the implementation will be challenging. ICZM can be supported by the development of appropriate decision support systems; i.e., in the form of conceptual models allied with the presentation of geo-spatial data in Geographic Information Systems that can be used to identify what would seem to be the most appropriate use of marine ecosystems. The term 'use' also includes non-exploitive activities particularly in areas that have high intrinsic natural value or have some protection conferred by legislation (e.g. National Parks).

The social science dimension is an important component on the issue of ICZM. Application of social science principles will facilitate a better understanding of the expectations of different stakeholders competing for space and resources in coastal areas and help establish a consensus among relevant users. This aspect has been addressed above (e.g. EVAD, Byron *et al.*, 2011).

Sustainability by definition and in application must include consideration of planning for multiple impacts and identifying the likely challenges posed by existing and future development and conservation (general sense) needs. To this end, sustainability therefore refers to the ability of a society to continue functioning in the future without being forced into decline through exhaustion or overloading of key resources upon which society's systems rely (Frankic and Hershner, 2003). While, proponents of aquaculture propose that the accelerated development of aquaculture in a sustainable fashion is a realistic goal, managers must be confident that the checks and balances are in place to ensure that the level of impact observed is acceptable and within allowable thresholds. Consistent with the broad view offered above, the focus for aquaculture development should be to manage existing activities and proposed expansions in coincidence with other activities in marine systems such that the management actions are fully integrated, and that any impacts will be at a minimum, neutral on both natural and social ecosystems (Byron *et al.* 2011).

Ideally, a sustainability indicator applicable to aquaculture should be able to incorporate all information in a system, identify what the goals (global vision) for the system are, and evaluate both positive and negative aspects of any proposed development. It is apparent that in order for managers to apply a system-wide view of sustainability, they would have to take into account a broad range of pressures and would define clearly what might be permissible and acceptable (i.e. social carrying capacity guided by legislative or policy drivers). Such an initiative would have to consider both spatial (ICZM) and temporal (LCA) considerations of pressures (activities) and sensitivities. The development of management systems must be informed by a clear notion of an acceptable endpoint that would be either defined as the level that a particular activity (or range of activities) might be carried out in the marine environment or the maintenance of a specific condition of an environmental feature (environmental standard). It would appear that progression towards truly sustainable practices is hampered when there is a clear need for interdisciplinary actions but there is little scientific knowledge to inform these actions. As identified, the mechanism towards identifying sustainable activities in the marine environment will be progressed when clear policies are elucidated and an inclusive approach is adopted reflecting fully legislative requirements and the views of all stakeholders.

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5 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 (ToR d)

Evaluation of the outputs of a number of Integrated Multi-Trophic Aquaculture System projects has been covered by WGEIM in recent years and will continue to be evaluated by the group as this new production approach transitions to commercial operations. In 2012, we update our IMTA review document on the Benefits and Legal Aspects, and add a discussion of outstanding and unresolved issues that will ultimately determine the efficacy of this ecological approach in a commercial-scale setting. The commercial application of IMTA will need to address these challenges, with the resulting environmental performance having implications to farm management – including regulatory compliance.

Introduction

In mono-specific fed aquaculture, such as fish cage aquaculture, increased amounts of organic matter, dissolved and particulate nutrients loads, particularly organic phosphorus and nitrogen (in the form of ammonia) may encourage eutrophication with negative consequences for pelagic and benthic communities, including macrofauna, meiofauna, seagrasses and/or bacteria. Accumulation of organic wastes (fish faeces and waste food) under aquaculture farms may also induce local organic enrichment. Estimates suggest that up to 40% of the feed provided to fish could become organic waste in the form of uneaten pellets and faeces (Gowen *et al.* 1994) although current practices have, for the most part, reduced such loading as it is not economically or ecologically prudent. Sediment organic enrichment may lead to increased oxygen uptake, ammonium release and sulphate reduction and a decrease in the abundance, biomass and diversity of benthic invertebrates at farm sites as compared to reference sites (Hargrave 2005). There is thus a clear need to reduce the environmental effects of aquaculture to maintain the sustainable development of this industry. One promising approach is the development of modern polyculture, appearing in the literature as the concept of a multiple species integrated system for sustainable coastal production (Brzeski & Newkirk 1997) or integrated multi-trophic aquaculture (IMTA) (Chopin *et al.* 2006). The most common IMTA approach combines fed aquaculture (fish) with extractive dissolved inorganic aquaculture (seaweed) and extractive particulate organic aquaculture (shellfish). This is based on the principle that the by-products (wastes) from one resource become inputs for another. A number of studies are currently testing the IMTA approach and early results show considerable potential for the bioremediation of nutrient-rich waters (Angel 2004). Most IMTA studies to date concentrate on the removal of dissolved and suspended-particle wastes and little effort has concentrated on reducing the impact of the particulate matter settling onto the underlying sediments. Integrated aquaculture may also benefit from the inclusion of detrital feeders (Cheshuk *et al.* 2003, Neori *et al.* 2004) that may be used as additional crops and/or for bioremediation. Benthic species that could benefit from the organic matter derived from the fish cages and shellfish cultivation, such as sea cucumbers, sea urchins, pearl oysters, flounder, nereid and sabellid polychaetes, clams, and grey mullet are currently being evaluated using different methods ranging from constraining the organisms in cages to allowing them to be free to roam. There are two main benefits from integrated aquaculture: mitigation or bioremediation of environmental impacts and increased profitability by extending yields (Brzeski & Newkirk 1997). Discussions about the outputs of IMTA systems highlight that the viability and efficiency of complex multi-trophic systems remain to be validated. Various aspects must be taken into account when evaluating the outputs of integrated systems, including nutrient budgets and mitigation, as well as (Whitmarsh *et al.* 2006), social (Barrington *et al.* 2010), legal (White & Glenn 2006) and commercial (Whitmarsh *et al.* 2006) ones. Some of these aspects have been discussed in previous ICES WGEIM reports (from 2005 to 2008). The goal of the present paper is to discuss 1) the benefit of using heterotrophic species (concept of zooremediation, Gifford *et al.* 2007) as a co-cultured species for environmental mitigation, including biofiltration of farm-derived organic loading, oxygenation of organically enriched sediments through bioturbation, and the filtration of viruses and other pathogens; and 2) the legal aspects of co-culturing two or more species in the same area.

Mitigation Benefits

An increasing number of experiments are underway to evaluate the efficacy of different combinations of species to mitigate the impact of aquaculture. Most studies evaluate the integration of two species (e.g., fish and shellfish; fish and macroalgae), although studies in Canada are currently testing the combination of three (fish, macroalgae and shellfish) and more (same groups with the inclusion of sea cucumbers, sea urchins and others) species. The goals (i.e., bioremediation, commercial production, etc.), environmental conditions, and methods used to evaluate the efficiency and viability of the integrated systems are variable, making generalisations difficult (see examples of zooremediation in Table 2).

Nutrient Pathways & Residual Concentrations

The fate of both organic particulates and dissolved nutrients released from cage cultivation of finfish through waste feed, excretion and the production of faeces is generating increasing interest in potential for utilisation (Reid *et al.* 2009). The proportion and/or scale of these particulate organic and dissolved nutrient wastes are dependent on many factors, including feed type (i.e., dry vs. moist pellets vs. trash fish), fish species being cultivated, and husbandry/management practices employed at the farming location (Islam 2005). For modern intensive fish farming (i.e. Salmonid production in Norway, Canada and Chile), only 5% of feed is lost to the environment, with the majority of particulate organic and dissolved nutrient losses associated with excretion and faecal production (Cromey *et al.* 2002). Current estimates of particulate organic and dissolved nutrient losses to the environment from modern salmonid production with an FCR of 1.3 are estimated to be 38 kg of total N (25% dissolved and 75% particulate) and 5.5 kg of total P (32% dissolved and 68% particulate) and 195 kg of POM per Tonne of fish cultured (Stigebrandt *et al.* 2004; Reid 2009; Figure 1).

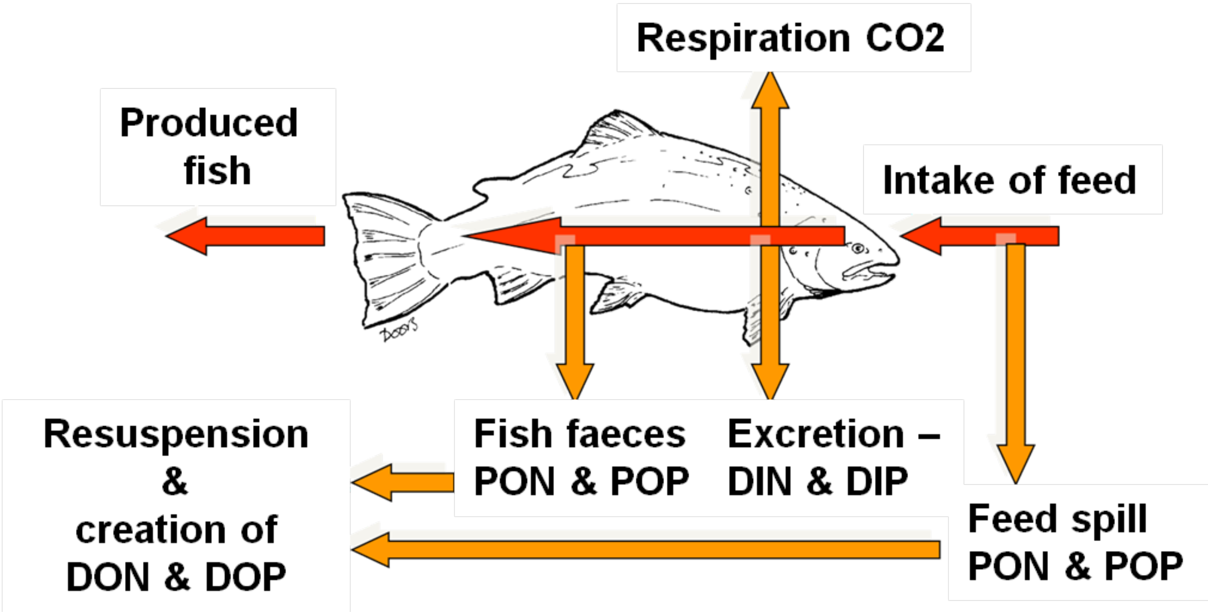

Figure 1. Typical particulate organic and dissolved nutrient loss pathways from finfish aquaculture (modified from Fredrikson *et al.* 2011).

The environmental fate of released particulate organic and dissolved nutrients has been documented with impacts on both pelagic and benthic systems. Accumulation of these particulate organic and dissolved nutrients in the marine environment negatively impacts the ecosystem, including eutrophication in pelagic systems and organic enrichment of benthic systems (Strain and Hargrave 2005). Implementing and optimising the performance of IMTA is theoretically based to maximise the uptake of released particulate organic and dissolved nutrients from extractive species to mitigate these environmental impacts. However, in practice, maximum uptake of both particulate organic and dissolved nutrients will be limited by 1) the type of extractive species chosen, 2) the assimilative capacity and standing stock of the chosen extractive organisms, 3) the structure and design of an optimal IMTA installation, and 4) site-specific physical and environmental parameters. It should be assumed, based on the above parameters, that a proportion of particulate organic and dissolved nutrients will be lost directly to the environment (Figure 2) and also indirectly through residual losses of particulate organic and dissolved nutrients from the extractive species (e.g. mussels releasing faecal material to the environment, which subsequently is re-mineralised in the environment). The degree to which residual losses of particulate organic and dissolved nutrient losses from the extractive species occurs (based on the scale of the extractive organism) may offset benefits from establishing an IMTA system.

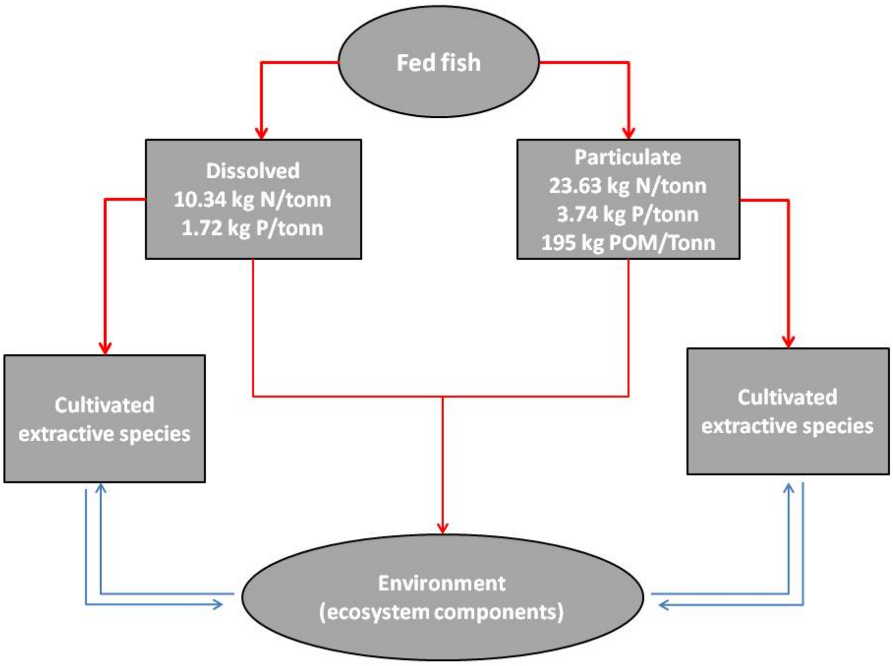

Figure 2. Simplified conceptual design of particulate organic and dissolved nutrient pathways and residual losses to the environment.

Filtration: conversion of nutrients into biomass

Co-Cultured Bivalves. One goal of IMTA is to reduce nutrient loading through conversion into valuable biomass. Bivalves are often used to this end in integrated polyculture system due to their high filtration capacity (Dame 1996) potentially allowing them to utilize organic waste as a food source and reduce impacts. Most studies involve the integration of mussel and oyster culture with salmon farming. Jones and Iwama (1991) studied the co-cultured of the oyster *Crassostrea gigas* and the chinook salmon (*Oncorhynchis tsawytscha*) in Canada. Oyster growth rates were three times greater at the salmon farm site and decreased with distance from the farm. They argued that the higher concentration of *Chl*-a and particulate organic matter measured at the fish farm site may explain, respectively, greater shell and biomass growth rates, relative to the reference site. If the goal of integrated aquaculture is to reduce nutrient loading, the extent to which the extractive co-species use farm waste must be evaluated. Differences in growth rates between farm and references sites may be due to a number of confounding factors, including variations in current regimes, shelter, etc. Isotopic analyses allow the efficacy of the mitigation strategy to be determined by evaluating the proportion of the extractive species' diet that originates from the farm. For example, Mazzola and Sara (2001) estimated that the particulate organic carbon waste from the fish feed provided 80% of the diet of adult clams, *Tapes* sp., cultivated in baskets adjacent to fish pans at 9m depth, 1m from the seafloor, and 50 % of the mussel *Mytilus galloprovincialis*' diet (suspended on a long-line at 3m depth). The benefit in this study was reduced environmental impacts due to fish pens and increased profitability by extending the yield. The same was shown by MacDonald *et al.* (2011), who concluded that increased growth of mussels grown close to salmon farms was due to increased availability of POM. Stirling and Okumus (1995) have also shown that the growth of mussels *Mytilus edulis* was greater at a salmon farm site in Scotland than in a mussel monoculture. They argued that higher POM and *Chl*-a levels at the salmon farm may support mussel energy retention during the winter. POM derived from fish aquaculture only contributed significantly to mussel growth during periods of low plankton production, which tend to occur in winter. During this season, shellfish placed close to fish cages could benefit from the additional POM and overcome growth restrictions in winter (Troell *et al.* 2003). However, other studies have observed no differences in growth rates between fish farm and reference sites, possibly due to: 1)-POM loading from fish cages being too diluted (Cheshuk *et al.* 2003), 2)-co-cultured species being grown at too great a distance from farm sites (e.g. 70 m distant in Cheshuk *et al.* 2003), and 3)-fouling organisms (e.g. mussel, tunicates, polychaetes) growing on the net and farm structures intercepting the POM before it reaches the co-cultivated species. Additionally, Navarrete-Mier *et al.* 2010 studied mussel (*Mytilus galloprovincialis)* and oyster *(Ostrea edulis)* growth close to finfish farms (Sea Bream and Sea Bass) in the Mediterranean and found no differences between farming sites and reference stations 1800 m away. The contradicting result from these studies shows the need for new studies to investigate the actual benefits for IMTA organisms and the design of such facilities to maximize bioremediation and growth of co-cultured organisms.

There are several project using marine micro and macroalgae as biofilters for waste water from land-based aquaculture of marine species (Abreu *et al.* 2011, Nobre *et al.* 2010). The use of filter feeders and deposit feeders such as mussels, abalone and polychaetes to remove waste from different land-based aquaculture activities is also an option (Stabili *et al.* 2010, Mao *et al.* 2009). Such projects may have more predictable benefits to the co-cultured species than IMTA facilities in the open environment, where nutrient losses are difficult to manage.

Although several projects include culture of kelp and other macroalgal species close to open cage farm IMTA, there are to date no published studies that show increased growth of seaweeds close to farms. The nutrient removal capacity of seaweed may vary with species, but are rather low compared to the emissions of nutrients from the farms (Abreu *et al.* 2011, He *et al.* 2008, Schuenhoff *et al.* 2006). Efficient removal of all nutrient emissions will thus depend on large scale seaweed farms, which would be difficult to place close to fish farms without altering the current pattern and thereby oxygen conditions in the fish farm. A possible solution to this dilemma would be, for example, area-based IMTA, where seaweed farms are situated independently from fish cage sites but still contributing to the net nutrient budget in the area.

<u>Fouling Communities</u>. Although fouling organisms may be considered as a threat for fish farming (reduction of water flow, extra weight on the net, etc.) they may also mitigate aquaculture impacts due to their high filtration capacity. Algae and invertebrates colonising nets, walkway floats and anchor lines could provide an important component of the food web, providing enrichment for a variety of marine species (Rensel & Forster 2007). Rensel and Forster (2007) used stable isotopes to determine how nutrients from a fish farm contributed to the diet of the fouling communities and showed that waste contributed significantly to the diet of caprellids, other amphipods and mussels. Lojen *et al.* (2005) and Cook *et al.* (2006) have also demonstrated that fouling communities colonising artificial structure may act as "biofilters" to remove fine particulates and dissolved nutrients derived from fish farms.

<u>Issues</u>. An important aspect of IMTA is to cultivate two or more species that are ecologically compatible, requiring similar environmental conditions and do not compete

for food and space in an aquaculture system (Kang *et al.* 2005). It is necessary to assess the oxygen demand of each component of the system. Heterotrophs may increase oxygen demand and decrease the oxygen budget of the fish culture. Respiration by autotrophs may also consume oxygen, although oxygen production during the day may compensate for night time consumption (Neori *et al.* 2004). Moreover, the biodeposition rates of each component of the system and the dispersal pattern of particulate and nutrients must be determined to evaluate the efficiency of an integrated system. For example, biodeposion in the form of faeces and pseudofaeces from farmed bivalves may increase local sedimentation rates and impacts on the benthic environment (e.g. Callier *et al.* 2006) and thus this should be taken into account when evaluating the environmental carrying capacity of a site.

Bioturbation

Whereas most IMTA studies concentrate on the removal of dissolved and suspended-particulate wastes, little work has focused on reducing the impact of particulate matter settling onto the underlying sediments. The deployment of deposit-feeders directly on the sea bed (invertebrates or demersal fish) may improve sediment quality under floating fish cages (Heilskov & Holmer 2001, Katz *et al.* 2002). Katz *et al.* (2002) found that rearing grey mullet on the organically enriched seafloor under a commercial seabream farm improved sediment quality by reducing organic matter, hydrogen sulphide and sediment oxygen demand. Grey mullet feed at the lowest trophic level and utilize detritus as a source of energy and carbon. Encouraging the decomposition of organic matter has also been attempted and achieved using a capitellid polychaete, *Capitella* sp., for marine bottom sediments below fish net pen culture (Tsutsumi *et al.* 2005). Deposit-feeders contribute to organic matter turnover by direct ingestion and assimilation of detritus and associated microorganisms (Heilskov & Holmer 2001). Moreover, benthic fauna induce sediment reworking (bioturbation), enhance oxygen penetration into the sediment, and stimulate mineralization of organic matter (Aller 1982). Furthermore, bioturbation may facilitate the recolonisation of reduced sediments by invertebrates by changing the physical and chemical characteristics of the sediment, as described by Gallagher *et al.* (1983) in their facilitation model, in which "early species prepare the way for later species in the successional sequence".

Diseases and parasites mitigation or caveat?

Diseases and parasites are often one of the first concerns that are raised in the implementation of IMTA. It is thought the addition of other species may either harbour or transmit diseases to the primary fed crop (e.g. salmon). Some of these objections are the result of a monoculture perspective. In actual fact, if the IMTA species used are native to the area, then they are usually already present on the site in close proximity to the animals as part of the fouling community. Therefore, it is not a case of presence or absence, but rather one of dose threshold and whether or not the species are capable of retaining or transmitting the disease (ICES WGEIM report 2008). Fouling communities and co-culture species could either be a threat or bioremediator, depending on the disease. For examples:

- Tan (2002) showed that biofouling should be considered as a risk factor for Amoebic gill disease (AGD) outbreaks as it may be a significant reservoir of the amoebic disease and may contribute to its spread.
- Skar & Mortensen (2007) studied the uptake of the pathogenic infectious salmon anaemia virus (ISAV) in mussels to investigate its potential transmission from fish to mussels and vice versa. Viruses are not regarded as a

natural food for bivalves but studies have shown that they may be efficiently trapped in mussel mucus strings during feeding. Mussels were not a likely reservoir host or vector for ISAV and they have been shown to destroy the virus.

- Ingestion of pathogens does not necessarily indicate that they remain viable as Paclibare *et al.* (1994) showed that the bacterial pathogen *Renibacterium salmoninarum* is removed and killed by the blue mussel, *M. edulis.*
- Milanese (2003) tested the capacity of the marine sponge *Chondrilla nucula* to retain the bacteria *Escherichia coli*. They showed that one square meter patch of this sponge can filter up to 14 l/h of sea water retaining up to 7×10^{10} bacterial cells/h. They suggested that *C. nucula* is a suitable species for marine environmental bioremediation in integrated aquaculture systems.

Legal Aspects

In considering the legal aspects of developing and managing IMTA it has become apparent that a clear definition of the approach is necessary. For this purpose the current definition has been formulated in support of the concept and the operation of such facilities.

- IMTA is the co-culture of two or more species that are complementary in their ecological roles (non-competitive for food or space), are of commercial value, and jointly function to minimize the organic and inorganic wastes generated from these components when cultured independently – resulting in a more environmentally efficient production system.

When is a site considered IMTA? For individual IMTA farm operations, the placement of the species should be such that the system design considers: 1) the dispersion and accumulation pathways of the organic and inorganic nutrient streams, ensuring the capacity to intercept, extract and retain the waste components among the system species; and 2) that the proportion of standing stock of the component species be of sufficient magnitude that the overall system function results in a measureable reduction in residual waste flux.

Regulatory Implications for IMTA

In discussion of the benefits and risks associated with progressing down a formalised IMTA approach to regional aquaculture development, a number of regulatory / legislative risks in licensing specific IMTA activities were identified. These are associated with certainty of environmental benefits of the combined activity where certain regulatory thresholds may be breached if these forecasted benefits are not achieved. The best example of such risks may be, for example, where increased finfish development may be applied for as part of an IMTA application in a region that is perceived to be at or close to capacity on the grounds of nutrient enhancement. Should regulatory authorities license the IMTA activity with no operational control on whether the shellfish/ seaweed components of the IMTA activity will operate successfully to extract the forecasted quantities of nutrients or even be developed? In such cases, new regulatory approaches may be required to ensure that the environmental benefits of IMTA are realised and that the regional ecosystem is not put at unacceptable risk from additional, un-mitigated nutrient inputs. These risks are only really relevant for IMTA systems in heavily developed areas and not for multi-species operations involving net benefits from nutrient cycling or in regions with significant available capacity.

From an industry perspective, IMTA is viewed as one approach that could mitigate the nutrient and particulate waste impacts of a fed aquaculture operation. If in fact IMTA increases site-specific environmental performance, then compliance with existing regulatory thresholds, in a performance-based management framework, would be achieved. As the efficiencies of IMTA systems improves then the possibility for increased component production will also be realized – a socio-economic benefit of the approach.

System Optimization

Minimizing the magnitude of residual nutrient loads generated from an IMTA system remains the largest design challenge for this production approach. The fate and effects of residual levels of nutrients in IMTA systems, given site-specific physiographic conditions, infrastructure design, component species selection/performance and stocking densities, may include increased productivity or anoxic systems with consequences at both ends of the downstream spectrum (water column and benthos). Various nutrient fluxes from the system components (e.g., from fish, bivalves and structures as well as benthos) may impact water column nutrient dynamics and thus the whole pelagic ecosystem. Future commercialization of IMTA will require careful consideration of a variety of issues that will concurrently optimize system functionality and thereby minimize the projected effects in the surrounding environment.

Site Selection

The physical attributes of an IMTA farm site will have a significant influence on system design and performance, affecting species selection, the bioavailability of the particulate and dissolved nutrient loads to the extractive components, and hence the overall efficiency of the system in terms of interception, extraction and conversion of these wastes into secondary culture products. The physiographic and oceanographic characteristics of the farm site are key factors in determining the ultimate performance of a proposed IMTA system. Tidal flow, in particular, has implications for infrastructure design and orientation (below), as well as for establishing the residency of the farm wastes and their bioavailability to the extractive species components – excessive water flows will increase residual waste flux and ultimately decrease the maximum proportion of the organic and inorganic wastes that could be extracted from the environment given optimal stocking and waste transport conditions. Bathymetry will also influence tidal flows, affecting waste dispersion patterns, directional influences such as downstream upwelling, etc.

Ecological Design

The number and selection of species will also affect overall IMTA system efficiency. Placement of appropriate extractive species that intercept each of the various waste streams (e.g. fine particulates, settleable solids, dissolved nutrients) will "account" for all of the potential pathways, and given the species-specific filtration rates, assimilative capacities, and stocking densities, will optimize the extraction potential for the system. The residual wastes, including that proportion not extracted by the secondary species plus those created by those species, will represent the fraction having a subsequent impact to the receiving environment.

IMTA systems can be designed at the individual farm level, considering the management of wastes generated within a single operation, or be configured within a larger, area-based configuration that supports an extensive approach to waste management.

Structural Considerations

In a fed-species IMTA system (e.g. fish) access to the animals for husbandry must be maintained, and hence system design must consider positioning of the extractive species components in such a manner as to prevent interference with fish husbandry activities (e.g. vessel access for net changes, fish entry/grading/harvesting, etc.) yet ensure that these components are positioned within the dispersion and accumulation pathways of the wastes. Physical oceanographic characteristics of the farm site will suggest the optimal locations for the extractive species structures, but the above farm logistical considerations will represent an additional source of waste losses through the IMTA system.

Issues associated with the addition of structures within an IMTA facility, including the containment and physical presence of extractive species, includes flow impedance within the system and the potential impacts to water quality (e.g., oxygen demand). Engineering of IMTA facilities will need to address these issues and explore options for facilitating the efficient transport of wastes from one system component to the next.

Recommendations

Remain a WG theme.

Table 2. Examples of zooremediation for aquaculture impacts in open water systems.

Study	Country	Cultivated species or model	Added Species	→ main goals = main conclusions
BIOFILTRATION				
(Ahlgren 1998)	USA, Alaska	*Oncorhynchus gorbuscha* (pink salmon) *Oncorhynchus keta* (chum salmon)	*Parastichopus californicus* (sea cucumber)	→ Convert the fouling debris into sea cucumber biomass = Sea cucumbers were feeding on fouling debris, cleaning the net. They assimilated debris more efficiently than their natural sediment diet. Study showed environmental and commercial implications.
(Cook *et al.* 2006) (in Israel, Lojen *et al.* 2005)	Scotland Slovenia Crete Israel	*Salmo salar* (Atlantic salmon) *Dicentrachus labrax* (sea bass) *Dicentrachus labrax* (sea bass) *Sparus aurata* (gilthead seabream)	Biofouling organisms on artificial structures	→ Use artificial structure colonised by biofouling communities as "biofilter" to remove fine particulates and dissolved nutrient derived from fish farms. = Artificial structure colonised by macroalgae, followed by heterotrophic filter-feeders (tunicates, poriferans, bryozoans) after 5- 6 months = Higher biomass was observed on artificial structures at farm sites compared to reference sites. Fish farm may have provided an enhanced food supply. Biofouling communities could induce a small reduction in nutrient loading into the environment.
(Cook & Kelly 2007)	Scotland	*Salmo salar* (Atlantic salmon)	*Paracentrotus lividus* (sea urchin)	→ Survivorship and production of sea urchin → Reduction of farm organic loading → Reduction of pressure on sea urchin wild stocks = Fatty acid analysis confirmed consumption of fish farm-derived POM by sea urchins. At farm site, higher survivorship, greater test diameter, and gonad development were observed compared to reference sites (50m and 2.5km). Sea urchins assimilated fish farm

				derived POM, reducing the dispersion into the ecosystem.
(Cheshuk *et al.* 2003)	Australia	*Salmo salar* (Atlantic salmon)	*Mytilus planulatus* (mussel)	→ To test if enhanced mussel performance and reduced organic enrichment resulted from integrated mussel-salmon culture = No observed difference in growth, due to either solid waste (feed particle and faeces) too diluted, mussels cultured too far from the fish farm (70,100m compared to 500,1200m)
(Gao *et al.* 2006, Gao *et al.* 2008)	Hong Kong, China	*Epinephelus awoara* (grouper) *Lutjanus russellii* (snapper) *Acanthopagrus latus* (seabream)	*Perna viridis* (green-lipped mussels)	→ Feasibility and capacity of using the green-lipped mussel *Perna viridis* as a biofilter to remove farming wastes from fish rafts → Quantify the contribution of respective food sources to assimilation in mussels using stable isotope and fatty acid analyses. = Mussels co-cultured with fish, filter and assimilate fish feed and fish faeces = annual nutrient assimilation capacities of a 70 mm mussel for carbon, nitrogen and phosphorus were 1476.9, 160.3 and 36.7 mg, respectively. Based on the practical culture density of mussels in southeast Asia, the assimilation capacity has the potential to remove fish farm wastes at mariculture sites
(Jones & Iwama 1991)	Canada, British Columbia	*Oncorhynchus tshawytscha* (chinook salmon)	*Crassostrea gigas* (pacific oyster)	→ Determine whether co-cultured mussels filter POM coming from the fish farm = Growth 3x greater at farm site than control site. Growth rates decline with distance from farms. Chl*a* and particulate organic matter (POM) greater in the pens. Shell growth dependent on Chl*a* level and growth rates more dependent on POM

(Mazzola & Sara 2001)	Mediterranean	*Dicentrachus labrax* *Sparus aurata* (gilthead seabream)	*Mytilus galloprovincialis* *Tapes* sp. (clams)	→ Determine whether co-cultured bivalves filter fish farm POM = Stable isotope analysis showed that POC waste from fish feed provided 80% of the adult clam diet (basket at 1m from seafloor, 9m depth) and 50% of the mussel diet
(Paltzat *et al.* 2008)	Canada, British Columbia	*Cassostrea gigas* (pacific oyster)	*Parastichopus californicus* (sea cucumber)	→ Growth and production of sea cucumbers → Test the utilization of oyster biodeposits as food source by *P. californicus* = Co-culture system would both reduce the amount of organic deposition underneath shellfish farms and produce a secondary cash crop.
(Slater & Carton 2007, 2009, Slater *et al.* 2009)	New Zealand	*Perna canaliculus* (greenshell mussels)	*Australostichopus mollis* (sea cucumber)	→ to examine the survivorship and growth of *A. mollis* → to reduce the benthic impacts of mussel farming = 91% survivorship + enhanced *A. mollis* growth compared to reference = Adult *A. mollis* consumed mussel farm-impacted sediment (6.70 g ±1.59 wet weight mussel sediment d^{-1}) = *A. mollis* (through grazing) reduce the accumulation of organic carbon and phytopigments associated with mussel biodeposition (tank based experiment)
(Stirling & Okumus 1995)	Scotland	*Salmo salar* (Atlantic salmon)	*Mytilus edulis* (blue mussel)	→ to compare growth, biomass and production of mussels suspended between salmon cages with similar populations at nearby mussel farms = Shell length greater in the salmon farm than in mussel monoculture. POM and Chl*a* higher at salmon farm may support mussel energy retention during winter.
BIOTURBATION				
(Porter *et al.* 1996, Katz *et al.* 2002, Lupatsch *et*	Israel	*Sparus aurata* (Gilthead seabream)	*Mugil cephalus*	→ Improvement of sediment quality under seabream cages in placing benthic feeding fish species

al. 2003)			(Gray mullet)	= decreased organic matter, hydrogen sulphide and sediment oxygen demand. Grey mullets feed at the lowest trophic level and utilize detritus as a source of energy and carbon
(Tsutsumi & Montani 1993, Tsutsumi 2007, Kinoshita *et al*. 2008)	Japan	*Pagrus major* (red sea bream)	*Capitella* sp. (polychaetes)	→ Proposed a bioremediation method for the treatment of the organically enriched sediment with artificially cultured colonies of the *Capitella* species = Rapid *Capitella* population growth, enhanced decomposition of organic matter = promising approach for minimization of the negative effects of fish farms.
(Zhou *et al*. 2006)	China	*Chlamys farreri* (Zhikong scallop) *Argopecten irradians irradians* (bay scallop) *Crassostrea gigas* (Pacific oyster)	*Stichopus japonicus* (sea cucumber)	→ To determine whether the deposit feeder *S. japonicus* can feed on bivalve biodeposits and determine its survivorships = *S. japonicus* co-cultured with bivalves grew well = Bivalve lantern nets can provide a good habitat for sea cucumbers co-culture of bivalve molluscs with sea cucumbers may provide an additional valuable crop with no additional inputs

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6 Review and report on the use of seed stock quality criteria in mariculture and their applications in term of ecological performance (ToR g)

6.1 Introduction

The quest by humans to domesticate animal and plant species to improve food production by means of care, feeding and breeding has been ongoing for several centuries. In the terrestrial environment, over 90% of the species used by humans for food are considered to be domesticated, while in the aquatic environment the proportion is estimated at only 3% (Duarte *et al.* 2007). This proportion, however, is on the rise with the aim of increasing benefits while minimizing the risk associated with domestication of aquatic species for farming purposes. This is particularly the case for finfish species, where the majority of seedstock originates from hatcheries. For shellfish species, there is a growing dependency on hatchery production, but the majority of seedstocks are still collected from the wild (WGMASC 2004). One of the key areas of domesticating aquaculture species is improving seedstock quality. On the benefit side, the emphasis is to maximize profitability by improving productivity in terms of growth, survival and product quality. On the risk side, the main issue has been the potential impacts of escapees on wild populations. The escapee issue has been reviewed, particularly for salmonid and non-salmonid fish species, in previous reports of the WGEIM (ICES 2005, 2006). More recently, Legatt *et al.* (2010) provide an overview of the pathways of effects of escaped aquaculture organisms (specifically finfish and bivalves) on natural ecosystems in Canada. We should also note that disease concerns have received considerable attention for finfish aquaculture.

Improvements in efficiency, in terms of both economic competitiveness and the management of ecological footprints in aquaculture, continue to be a prime objective of governing agencies, aquaculture producers and other stakeholders. Borrowing from Diamond (1998), domestication of animals should include the following criteria:

1) Flexible diets
2) Environmental adaptability
3) Density independent
4) Minimize reproductive output
5) Balancing economic benefits with environmental performance

To date, however, most of these criteria have mainly addressed economic benefits and the issue of environmental performance has been largely ignored. With respect to seedstock quality, environmental performance is viewed as the size of the ecological footprint, from biological, chemical and physical perspectives.

For shellfish aquaculture, due to the high degree of interaction between cultured species and the environment, the environmental performance of domesticated molluscan species could present risks and benefits equal to or greater than those due to escapees and productivity.

For finfish, the selection of seedstocks to better perform in host environments has already received considerable attention, but mainly as a mean of minimizing the impacts of escapees. Less attention has been devoted to the topics of food conversion and oxygen demand to minimize the environmental footprint associated with the practice.

The aim of this paper is to investigate the options of integrating environmental performance (footprint) in the development of seedstock quality criteria while continuing to focus on economic performance (profitability). Environmental performance is divided in two categories i) intake and ii) output.

6.2 Environmental Implication

6.2.1 Intake

Starting with a common denominator, oxygen intake from finfish, shellfish and plant species can vary considerably in relation to their physiological fitness. This feature can be easily managed through the seedstock selection but may impact the profitability of aquaculture operations, mainly in terms of the production cycle. For some species, however, it can be a win-win situation. Tremblay *et al.* (1998b) have shown that mussel (*Mytilus edulis*) with high physiological fitness, based on genetic characteristics, can consume 60% less oxygen during their standard metabolic rate while demonstrating higher growth performance.

For mollusc and plant species, intakes have been focused on particulate matter (organic and inorganic), including plankton, and dissolved nutrients. Here again, selecting for more efficient seedstocks in term of bioenergetics and assimilation may lead to increased productivity while reducing the ecological footprint of aquaculture activities. In some cases, however, the gain in productivity can be directed toward gamete production rather than somatic tissue growth, which can lead to lower yields and larger output (see below) (Rodhouse *et al.* 1984). Here, selecting for sterile seedstocks (i.e. polyploidy) may become less taxing on the natural resources and thereby reduce the ecological footprint while improving productivity (Hand *et al.* 2004).

6.2.2 Output

The issue of bio-deposition has received the bulk of the attention in terms of biological output from aquaculture in general. This can include both the production of organic waste (feces/pseudo-feces and fall-off of product to the seafloor) and feed deposition, although seedstock quality has very minimal effect on the latter (EC, 2009; McKindsey *et al.* 2006).

Nutrient output has also received considerable attention, both for finfish and shellfish. These are mainly in the form of soluble nitrogen and phosphorus products. In fed aquaculture, such as finfish and crustacean, this can have direct and indirect impact on the environment (Ackefors and Enell, 1990). In extractive aquaculture, such as grazing bivalves and marine plants, the impact of nutrient release is considered to be negated by removal through feeding and harvesting (Newell *et al.* 2005; Beck *et al.* 2011). Although the concept of Integrated Multi-Trophic Aquaculture (IMTA, see section in this WGEIM report) is addressing some of these concerns, the use of seedstocks with reduced output can assist in minimizing the ecological footprint of aquaculture.

In contrast to nutrient releases, reproductive outputs have received very limited attention. The management of these emissions, through seedstock quality, could not only improve the acceptability of the aquaculture industry, but could in fact contribute largely to their profitability. Reducing reproductive efforts in farmed animals is a strategy that has been widely used in the agri-food industry to improve productivity, either by focusing growth on valuable assets or by reducing loss related to producing offspring. In aquaculture, the release of gametes can also be at a high bio-energetic cost with low returns (recruitment). Weight loss related to reproductive efforts in bivalves is generally estimated at 30–40% (Myrand *et al.* 2000: Bourles *et al.* 2009: Maar *et al.* 2009). The ecological footprint of this reproductive effort is both in terms of production cost and the release of a large biomass of reproductive material to the water column, over a short time period. To our knowledge, the ecological impact of the latter effect has not been investigated. Similar arguments can be made for finfish aquaculture, when these are reproductively active during their production cycle.

6.3 Management consideration

6.3.1 Natural seed collection

This mainly applies to the shellfish industry and particularly to molluscan species. Although hatchery production is becoming more attractive, the large majority of bivalve farms, worldwide, depend on seed collected from the wild (WGSA 2004). Here, supply tends to be relatively high and can be highly variable, both in terms of quality and quantity. This has led the industry to overstock their farms, with low expected returns, or to occupy large areas to ensure maximum returns. The option for managing seedstock quality in this instance is very limited.

6.3.1.1. Seed collection site: Seed source has been the most widely used criteria. For instance, some areas tend to produce higher quality seed. In Atlantic Canada, there have been several studies to investigate seed quality in relation to their sources (Mallet *et al.* 1983; Tremblay *et al.* 1998a; Tremblay *et al.* 2011). For mussels, the species composition (*M. edulis*, *M. trossulus M. galloprovincialis* and hybrids) and the level of heterozygosity are sometime used to score seedstock quality.

6.3.1.2. Seed collection time: Time of seed collector deployment aims to optimize the quantity of collection and reducing the impact of competing or predatory species. Recently, however, it has been shown that the timing of collector deployment can also have an impact on seed quality, both with respect to species composition and quality (Toro *et al.* 2002).

6.3.1.3. Culling: For the most part, culling seed is based on size and occurs at the initial stocking phase. For instance, naturally collected mussel and oyster seeds are often selected based on size before being socked or deployed in cages (LeBlanc *et al.* 2008). However, there are examples of effective culling efforts post-stocking. In Spain, mussel farmers have a re-socking activity (Perez-Camacho *et al.* 1991). The initial socking event will have a first culling effort and will lead to large seed socks with densities exceeding 5000/m. The second socking event provides the farmer another opportunity to cull mussels based on size, before socking at a density of <300/m. In addition, the first socking event provides a difficult environment for the seed, which is believed to challenge (destroy) the less fit animals.

6.3.2 Hatchery seed production

Traditionally, seed production in hatcheries has mainly addressed supply issues from a temporal perspective to a reliability objective. They are also key to the genetic improvement or domestication of farmed aquatic animal, for economic goals and could also assist in achieving critical environmental goals.

Hatcheries' performance can also directly contribute to reducing the ecological footprint of aquaculture by proper management of effluent discharges. This can be greatly influenced by seedstock quality in terms of feeding and disease control. Also, maintaining high water quality can reduce fish stress and improve production efficiency.

6.3.2.1 Broodstock selection

To date, hatchery production aims at 1) securing adequate supply of seedstock and 2) improving the yield of farmed species. Starting with broodstock selection, the focus has been on achieving fast-growing animals, with high survival traits (i.e. disease resistant). Criteria for improving food conversion efficiency can also be considered. Although these three criteria can offer valuable economic benefits, they also offer great opportunities for minimizing the ecological footprint of farms both in terms of intake and outputs.

6.3.2.2 Genetic improvement

This is clearly the most important factor in addressing the potential role of seedstock quality for reducing the ecological footprint of aquaculture, yet it is clearly overshadowed by the economic goals of the hatchery industry. Dunham *et al.* (2001) provided a comprehensive review of the status of aquaculture genetics, exploring the topics of Crossbreeding, Hybridization, Poliploidy, Sex Manipulation, Gynogenesis and Androgenesis, Transgenic and Environmental Issues. Unfortunately, the latter only touches on escapees and farm-wild fish interactions, without exploring the potential benefits of genetic improvement for minimizing the impact of intakes and outputs from farms. It is clear that without sound bio-economic evidence on the risk of neglecting these environmental considerations (intake and outputs), seedsock development will continue to evolve around profitability and consumer acceptability issues with little to no consideration for environmental sustainability.

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7 Collaboration between the WGEIM and WGMASC to revitalize the issue of sustainability in aquaculture and provide clear recommendations for SCICOM (ToR h)

Discussion issues:

i) Setting up a new EG on the topic that will supplant or compliment WGMASC and/or WGEIM, or suggesting a way to revitalize the issue through the existing EGs;

ii) How to involve finfish scientists more in the EG(s);

iii) A work plan for the new/revitalized EG(s) aiming for a start-up meeting during ASC 2012 following the aquaculture sessions.

7.1 Joint meeting between WGEIM and WGMASC

The ICES Science Plan includes obtaining a better understanding of the interactions of human activities with ecosystems, including carrying capacity for aquaculture and ecosystem interactions in aquaculture. Both the WGEIM and the WGMASC have worked on issues relating to both of these structures throughout their histories. That being said, there is a wish from SCI COMM that the two groups occupy a clearer advisory role on sustainability for aquaculture. There are a number of various challenges with respect to accomplishing this, including:

1) Increased demands for advice on sustainability. Aquaculture is seen to have great impacts on the environment by the public. There is increased pressured from other human activities and all such activities must be considered together as cumulative effects. There is a move to including marine spatial planning (impacts, ecosystem vulnerability, relative risk/impact) in marine spatial planning. There is also variation with respect to advice backed by science, clear advisory processes, and external quality control among industries (compare fisheries, petroleum, aquaculture, mining) which may lead to increased conflicts.

2) Quality control of advice. Some member states (e.g., Norway) wish to have advice on aquaculture developed to obtain better advice on sustainability of aquaculture operations.

3) Attracting finfish aquaculture scientists. WGEIM has struggled to engage finfish scientists. Perhaps scientists do not see ICES as being interesting enough.

Thus, SCICOM has tasked the WGMASC and WGEIM to collaborate to develop a plan to establish a mechanism to develop an EG on “sustainability in aquaculture” to address the above issues. Ideally, a process would be developed so that clear requests for advice would be formulated by member states so that clear risk assessments could be undertaken by some form of EG or management structure of EGs on sustainability. To this end, the EGs held joint sessions within a joint meeting of the two groups in March 2012 in Sopot, Poland. After lengthy discussions, it was agreed to, as a first step, develop a list of country-specific priorities with respect to sustainability in aquaculture. A table was thus developed listing identified issues that will be circulated to member nations to gauge their level of concern and knowledge of the identified issues (see Annex 4). Second, a table of pros and cons of various management structures (see Annex 5) of the existing EGs, creation of a new or multiple new EGs or transformation of existing ones was developed to be debated later on in the joint session. It was hoped that this would guide the decision as to the most logical way forward to better address issues surrounding sustainability in aquaculture. Third, a note was drafted to send to member countries to solicit requests for science advice within the scope of knowledge of the EG(s) (see Annex 6). It is anticipated that requests coming directly from member countries will focus a portion of future ToRs for the group(s), specifically with respect to the development of risk assessments for various issues relating to the sustainability of various aspects of aquaculture. It is also anticipated that some ToRs will remain that will be member-driven to meet individual member's needs.

Debate on the potential management structures to ensure that issues relating to sustainability in aquaculture and that a critical mass of people with experience related to fish culture would participate in the process resulted in 3 possible scenarios. These are listed in order of preference based on our deliberations (see Table 2). About 90% of the total memberships of the WGMASC and WGEIM support the first option but it is anticipated that the SSGHIE will have final say on the ultimate management structure.

The issue of participation by finfish culture-related participants seems to have been solved as a number of new recruits to the WGEIM have expressed their interest in contributing to this or a combined EG that is more focused on end user-related requests. It is also anticipated that these members will strive to involve their counterparts in other countries.

An initial meeting of the anticipated new EG will be held at the ASC in Bergen in September to establish ToRs for the new EG (based on current WGMASC and WGEIM ToRs and results from the survey on member country interests and needs).

Annex 1: List of participants

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Annex 2: WGEIM 2012 Revised Agenda

Agenda - WGEIM annual meeting, 20 – 23 March, 2012, Institute of Oceanology Polish Academy of Sciences, 55 Powstańców Warszawy Street, Sopot, Poland

host: Roman Wenne, WGMASC

***Note that this will be a joint meeting with WGMASC with participation by SSGHIE**

Tuesday, March 20, 9:00-18:00

9:00-10:30
- Welcome from IO PAS by Prof. Janusz Pempkowiak, Director, and housekeeping information by Roman Wenne
- Introductory round and adoption of the agenda
- Presentation of Plan for new Expert Group on Sustainable Aquaculture by Eric Olsen (chair SSGHIE)
- Discussion on Plan for new EG Sustainable Aquaculture (ToR h)

10:30-11:00
- Health break

11:00-12:30
- Drafting **of recommendation to SCICOM (ToR h) on:**
  - i) Setting up a new EG on the topic that will supplant or compliment WGMASC and/or WGEIM, or suggest how to revitalize the issue through the existing EGs
  - ii) How to involve finfish scientists more in the EG(s)
  - iii) A work plan for the new/revitalized EG(s) aiming for a startup meeting during ASC 2012 following the aquaculture sessions

12:30-13:30
- Lunch

13:30-15:00
- WGEIM meeting
  - Presentation of 2010 WGEIM ToRs (a, b, d, and e) by chair;
  - Identification of ToR memberships, leads, and rapporteurs for each ToR;
  - Establish work plan for remainder of week;
  - Identification and discussions of emerging issues (ToR a);
  - Presentation of theme session at Bergen ICES ASC

15:00-15:30
- Health break

15:30-17:30
- Split up in subgroups to address 2012 ToRs

17:30-18:00
- Wrap-up discussion

Wednesday, March 21, 9:00-18:00

9:00-10:00
- Plenary – brief overview of work status

10:00-10:30
- Plenary discussion on ToR i (Collaboration with other EGs in relation to ICES Science Plan)

10:30-11:00	• Health break
11:00-12:30	• Reconvene for subgroup deliberations
12:30-13:30	• Lunch
13:30-15:00	• Reconvene for subgroup deliberations
15:00-15:30	• Health break
15:30-17:30	• Reconvene for subgroup deliberations
17:30-18:00	• Wrap-up discussion
Evening	• Dinner offered by host…

Thursday, March 22, 9:00-18:00

9:00-10:30	• Plenary – revisit ToR h and deliberate on fate of EGs
10:30-11:00	• Health break
10:30-12:30	• Deliberate on fate of EGs
12:30-13:30	• Lunch
13:30-14:30	• Deliberate on fate of EGs
14:30-15:00	• Plenary – brief overview of work status
15:00-15:30	• Health break
15:30-17:30	• Reconvene for subgroup deliberations
17:30-18:00	• Wrap-up discussion

Friday, March 23, 9:00-13:00

9:00-9:30	• Plenary – brief overview of work status and discussion of draft WGEIM report (includes crafting Executive summary, drafting recommendations, future ToRs)
10:00-10:30	• Discuss potential locations
10:30-11:00	• Health break
11:00-12:00	• Discuss potential contributions to Theme session at ICES ASC, Bergen
	• Discuss meeting of new (reformed?) EG on sustainability at ICES ASC, Bergen
12:00-12:30	• Meeting adjournment
14:00-…	• Excursion to Gdansk: old town and Central Maritime Museum (http://www.cmm.pl/siedziba.php?main=hist&mid=8)

Annex 3: WGEIM terms of reference for 2012 meeting

2011/2/SSGHIE16 The **Working Group on Environmental Interactions of Mariculture** (WGEIM), chaired by Chris McKindsey, Canada, will meet jointly with WGMASC in Sopot, Poland, 20–23 March 2012 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 by ICES member states;

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

h) Collaborate with WGMASC to discuss how to revitalize the issue of sustainability in aquaculture. A clear recommendation for SCICOM should be developed. Issues to discuss are:

   iv) Setting up a new EG on the topic that will supplant or compliment WGMASC and/or WGEIM, or suggesting a way to revitalize the issue through the existing EGs

   v) How to involve finfish scientists more in the EG(s)

   vi) A work plan for the new/revitalized EG(s) aiming for a startup meeting during ASC 2012 following the aquaculture sessions

i) Evaluate potential for collaboration with other EGs and other ICES initiatives in relation to the ICES Science Plan and report on how such cooperation has been achieved in practical terms (e.g. joint meetings, back-to-back meetings, communication between EG chairs, having representatives from own EG attend other EG meetings).

WGEIM will report by 5 May 2012 (via SSGHIE) for the attention of SCICOM.

Supporting Information

Priority	The activities of the WGEIM are fundamental to the work of the SSGHIE and STIGMSP. 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 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. ToR h) To revitalize and expand the aquculture science of ICES a new working group on sustainability in aquaculture will be planned to develop its ToRs at the ASC 2012 following the two aquaculture sessions. WGEIM should, together with WGMASC, plan and chair such a meeting in close collaboration with the chairs of the aquaculture sessions at the ASC2012. ToR i) This is a general ToR for all Expert Groups under SSGHIE.
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, WGITMO, and WGPDMO, and the work is relavant to WGMPCZM.
Linkages to other organizations:	The work of this group is undertaken in close collaboration with the DFO, GESAMP, BEQUALM, OIE, EU, EAS, PICES

Annex 4: Overview of country-specific interests (I) and knowledge (K)

Please classify the level of Knowledge and Interest levels for each of the below issues that were identified by the EGs. For each issue for which you have a heightened level of interest, please provide limited text (max 1 paragraph) to outline your specific concerns. Other issues may be listed as needed.

Interest

1. None
2. Low (low now or not anticipated to become important in medium-term)
3. Moderate (non-critical issues or not near-term interest)
4. High (critical issue at this time or in near future)

Knowledge

1. Non-existent, best guess
2. Limited, non-peer-reviewed
3. Good, peer-reviewed and not specific to region of interest
4. Excellent peer-reviewed and regional and elsewhere

Issue	Country name:		
	I	K	Comments
Shellfish			
1. Human health			
2. Diseases			
3. Mortality (disease, other)			
4. Pollution and contaminants			
5. Certification			
6. Diversification			
7. Regulations			
8. Economic efficiency			
9. Predator management			
10. Pest management			
11. Exotic species			
12. Hatchery production (genetics and public perception of using artificial organisms)			

13. Spat supply			
14. Carrying capacity			
15. Artificial upwelling to improve bivalve growth			
16. Bioremediation (e.g., nutrient extraction)			
17. Management tools - Thresholds and indicators			
18. Management tools - Dealing with uncertainty associated with science advice			
19. Management tools - Conservation areas (e.g., Natura2000)			
20. Spatial planning - maximize production			
21. Spatial planning - minimize user conflicts			
22. Spatial planning - minimize impacts			
23. Spatial planning - cumulative effects			
24. Interactions with birds			
25. Interactions with fisheries			
26. Ecosystem goods and services			
27. Off-shore issues (technology, site selection, impacts, carrying capacity)			
28. On-land culture			
29.			
30.			
Finfish			
1. Spread of sealice			
2. ISA (and other) transfer to wild fish			
3. Theraputant effects			
4. Regulation for theraputants			
5. Use of well boats for treatments			
6. Exotic species			

7. I&T			
8. Diversification for new species			
9. Interactions with wild stocks			
10. Escapees			
11. Sterile fish as mitigation			
12. Mitigation (IMTA) and how efficient is it, actually?			
13. On-land culture			
14. Closed containment			
15. Bioremediation via polychaetes, sea cucumbers, etc.			
16. Land-based, waste treatment, recirculating systems			
17. Wastewater treatment and production of algae, biofuels			
18. Management tools - Thresholds and indicators			
19. Management tools - Dealing with uncertainty associated with science advice			
20. Management tools - Conservation areas (e.g., Natura2000)			
21. Management tools - Habitat-specific monitoring issues (e.g., Maerl, seagrass, hard, soft)			
22. Spatial planning - maximize production			
23. Spatial planning - minimize user conflicts			
24. Spatial planning - minimize impacts			
25. Spatial planning - cumulative effects			
26. Carrying capacity			
27. Interactions with fisheries (e.g., lobsters, cod)			
28. Far-field issues with respect to nutrient enrichment			
29. Risk assessment use and how effective are they			
30. Use of feed (fish oil and mean consumption) and alternative aquafeeds			
31. Off-shore issues			

32.			
33.			
Other spp and methods			
1. IMTA			
2. IMTA for bioremediation			
3. New species (algae)			
4. New species (cucumbers)			
5. New species (polychaetes)			
6. New species (others)			
7. Interactions with fisheries			
8.			
9.			
General			
1. Dealing with uncertainty associated with science advice and how to extend to new site selection			
2. Climate change			
3. Ocean acidification (new EG)			
4.			
5.			

Annex 5: Retained options for new EG(s) to ensure that sustainability issues are adequately addressed

Option	Pro	Con
• Start a single new group on sustainable mariculture and finish both EIM and MASC (and include SGSA?)	• Attract new people and new questions for advice • Interaction between shellfish and finfish people, room for other organisms (algae, sea cucumbers)	• Less members for total group because of limitations placed on numbers of participants by some countries • Dilution of issues not related to sustainability • Group may become too big (difficult to manage and difficult to find venues) • Lose momentum in a well-functioning EG (MASC)
• Start two new groups, one on sustainable shellfish mariculture and one on sustainable finfish mariculture and finish both EIM and MASC	• Attract new people and new questions for advice • More interaction between former EIM and MASC members • No overlap between groups an greater critical mass for shellfish	• Less shellfish members for total group because of limitations placed on numbers of participants by some countries • Less interaction between fish and shellfish people • What to do with other organisms and IMTA? • Dilution of issues not related to sustainability • No expertise on socio-economic issues
• Keep it as it is, but hold joint meetings every second year	• No problem with number of members per country	• Low attendance by finfish people in EIM • Overlap between EIM and MASC

Annex 6: Letter to send to member countries to solicit requests for science advice within the scope of knowledge of the EG(s)

The rapid growth in aquaculture production around the world is causing concern and generating questions on complex and sometimes controversial matters, originating from many directions (regulators, managers, public, industry, NGOs, etc.). For the most part, these questions are related to aspects of the sustainability of this new agro food industry. Some of these questions are being addressed by the governing agencies within their own jurisdictions, and sometimes, the results of internal (national) scientific investigations and policies are challenged and can sometimes lead to increased conflict among the various stakeholders. In addition, national management is becoming increasingly affected by international rules and regulations.

ICES is a network of more than 1600 scientists from 200 institutes linked by an intergovernmental agreement, providing relevant, responsive, sound, and credible science and advice concerning marine ecosystems and their relation to humanity. During the past century, member countries (20) have relied on ICES to provide advice to help them manage the North Atlantic Ocean and adjacent seas, particularly for fisheries. More recently, some member countries have requested assistance from ICES on aquaculture related issues.

As per fisheries questions, ICES can provide a transparent and standardized process for reviewing how scientific information is applied in policy and providing expertise for advice on aquaculture issues. A need for such a process has been recognized for aquaculture in order to add more independence and credibility to science advice and reduce conflict with stakeholders.

ICES has several Expert Groups (EG) that have assisted member countries with aquaculture related inquiries in the past, including the EGs on Environmental Interactions with Mariculture, Application of Genetics in Fisheries and Mariculture, Integrated Coastal Zone Management, Pathology and Diseases of Marine Organisms, Socio-Economic Dimensions of Aquaculture, Introduction and Transfers of Marine Organisms, Marine Planning and Coastal Zone Management, and Marine Shellfish Culture.

ICES is presently considering putting more emphasis on aquaculture suistainability and provision of advice. , including the creation of an over-arching Group on Mariculture Sustainability, and a dedicated position in the Secretariat to promote and coordinate ICES activities with client organizations and member states in relation to mariculture.

Member states are encouraged to utilise ICES as an independent and efficient means to integrate international mariculture research and provide advice through a large numbers of expert groups, symposia, and an Annual Science Conference. Also, ICES can be a prime source of scientific advice on the marine ecosystem to governments and international regulatory bodies that manage mariculture in the North Atlantic Ocean and adjacent seas. For some specific examples of the type of advice given in the past see Annex X. (with examples of ToRs completed and publications, etc).

Annex 7: WGEIM draft terms of reference for 2013 meeting

The **Working Group on Environmental Interactions of Mariculture** (WGEIM), chaired by Chris McKindsey, Canada, will meet in Palavas, France, 18–22 March 2013 to:

a) Identify emerging mariculture issues and related science advisory needs to maintaining 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) Review and report on the impacts of mariculture on sensitive habitats. Review and report on methods to assess/monitor these habitats;

c) Review and report on approaches to assess/monitor impacts of mariculture in non-soft bottom habitats;

d) Review and report on the environmental effects of pest management in mariculture with an emphasis on i) therapeutant release, ii) waste management, and iii) propagule pressure. Ultimately, a risk assessment framework will be developed with respect to treatments for pests within a greater pest management framework. Treatment of fish lice and tunicates will serve as case studies. (Check with Simon Jones (WGPDMO) to see if they cover this);

e) Review and report on issues relating to ocean ranching of echinoderms within an IMTA context;

f) Review and report on issues relating to the attraction and repulsion of wild fish populations by finfish farms and of the impact of this on these populations, the individuals, and the human consumer;

g) Review and report on approaches to assess ecosystem services provided by mariculture;

h) Characterize ecological and genetic risks, real and perceived, associated with introducing foreign strains and species of finfish and shellfish and other invertebrates for aquaculture purposes to help inform policy development and decision makers and reduce conflict between aquaculture operators, regulators and other interested members of the public (traditional fisheries, NGOs, etc.);

Depending on the results from our analyses of priorities (Annex 4) and requests from member nations (Annex 6), other ToRs may also be developed to address more pressing needs. It is also anticipated that not all ToRs will be completed or even addressed in 2013. Rather, the EG will work on 2 to 4 ToR deemed to be of greatest interest to member nations and for which the membership of the WGEIM have the ability (i.e. knowledge) to address.

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) Over the past decade, there has been an emerging awareness and identification of numerous sensitive habitats/species (i.e. Maerl beds, coral reefs, eel grasses, sponge gardens, breeding/spawning grounds, etc.) in the marine ecosystem, which have important ecosystem functions. This increase in knowledge has resulted in the establishment and identification of these sensitive habitats/species as high conservation value by the Habitats Directive (92/43/EC) established in EU member states. With increasing aquaculture operations and siting of new farms there is increasing concern over the impacts of aquaculture to these sensitive habitats/species. However, there is a lack of scientific based knowledge quantifying the interactions of aquaculture activities and these sensitive habitats/species of high conservation value. Therefore, in the absence of such scientific based information, applying traditional risk assessments/analysis frameworks is difficult.

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

ToR d) Supporting information. The management of pest species in mariculture has received increased attention in the recent past, particularly in reference to sea lice management in salmon farms and tunicate management in mussel farming. The development of treatment regimes and methods has been mainly focused on the efficiency of control methods and therapeutants. To manage sea lice levels at marine cage finfish sites, aquaculture operators rely upon a number of therapeutant treatment products. These products are delivered either in-feed (e.g. SLICE® active ingredient: emamectin benzoate) or topically through bath treatment (e.g., Alphamax ™, active ingredient: deltamethrin). To manage tunicates in bivalve farms, farmers may apply a variety of chemical products (e.g. lime, vinegar) to product and/or equipment or use physical methods to remove/kill fouling tunicates. The active ingredients in therapeutants, regardless of their mode of application, may enter the aquatic environment through a variety of pathways (e.g. dissolution, particle transport and sedimentation) and thus may reside in the water column or accumulate in benthic ecosystems and expose non-target organisms. In bivalve culture, mechanical methods of tunicate removal may greatly augment the deposition of organic matter (dead and dying tunicates and other fouling species and product) to the sea floor within and around culture sites. The process may also encourage the liberation of propagules (larvae or fragments of colonial species) that may hasten the spread of invasive species. To date, little work has addressed these issues. Moreover, the risk associated with the various aspects of pest management has not been evaluated within a structured format such that decisions relating to treatment options are commonly made without regard to other possibilities. Greater certainty associated with the risks surrounding various aspects of pest management will support decisions relating to various treatment options.

ToR e) The use of economically valuable macroinvertebrates such as sea urchins or sea cucumbers, as the benthic component of an IMTA system, is attracting considerable industry interest. However, use of containment structures has been

	shown to be cost-prohibitive beyond that of juvenile rearing. The most efficient production approach for these animals, in terms of grow-out, is to deploy the juveniles over the seafloor, allowing them to have free range and to consume the organic waste stream (and deposits) not only from fish but from the extractive shellfish component of IMTA systems. The outstanding issues with the ocean ranching of these echinoderms include interactions with wild stocks (and fisheries), the potential impacts (displacement?) of existing habitat, and the required ranching densities needed to offset the waste fluxes. As a first step, a background paper will be produced outlining the general issues. Subsequent work will address certain identified issues in detail.. **ToR f)** An increasing number of studies has shown that the presence of a marine fish farm may affect wild fish in a given area. Fish farms may attract wild fish because of feed and other waste products associated with farms, altered communities associated with farms, and the physical structure of farms, which may offer alternate refuges or food sources. In contrast, anecdotal evidence suggests that some fish have altered their spawning and migratory behaviour to avoid areas with farms. With respect to the attraction of fish to farms, their consumption of waste products may alter the quality of the fish (size, condition, texture, flavour, etc.). It is largely unknown haw any of these factors differ at different life stages. In addition, the fate and effect of chemical residues (e.g., antibiotics and sea lice treatments) on these organisms and on human health if they are consumed are unknown. This Tor will examine issues relating to the attraction and repulsion of wild fish populations by finfish farms and of the impact of this on these populations, the individuals, and the human consumer. **ToR g)** The environmental interactions of mariculture are receiving more attention with respect to the negative impacts of the industry, despite the growing information on the ecosystem services that this activity can provide. This is particularily true for highly sensitive and stressed coastal ecosystems around the world. Well managed mariculture generally increases the net production of its host environment by maximizing the use of natural resources, from a physical, chemical and biological perspective. The aim of this ToR will be to review the negative and positive endpoints of mariculture and place them in a risk-assessment framework. **ToR h)** Aquaculture companies have, and will continue to seek access to better performing aquaculture strains, however, concerns centering on the potential ecological and genetic impacts of such introductions on local wild populations often prevents transfer requests from being granted. Characterization of risks involved with introducing foreign strains and species of organisms for aquaculture purposes would help inform policy development and decision makers and help to reduce conflict between aquaculture operators, regulators and other interested members of the public (traditional fishers, NGOs, etc.). There have been many published studies that have researched genetic interactions between cultured and wild salmonids (for both aquaculture and enhancement efforts), effects of these interactions on possible hybrid phenotypes, including growth and survival, reproductive interactions between wild and cultured fish, and escape mitigation. Likely a similar body of work exists for shellfish. It would be very beneficial to consolidate body of work to provide advice on the potential/perceived risks of introducing strains for culture. A review of measures to reduce or mitigate these risks would be a valuable addition.
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	ACOM

committees	
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 8: Recommendations

Recommendation	For follow up by:
1. The WGEIM recommends to flesh out identified emerging issues (ToR a) intersessionally and make suggestions for potential ToRs at the ASC in Bergen.	WGEIM SCICOM
2. The WGEIM recommends that issues relating to the sustainability of aquaculture have a strong social component and are best considered within the context of an Integrated Coastal Zone Management (ICZM) framework. The group thus supports the continuation of the Study Group on Socio- Economic Dimensions of Aquaculture (SGSA).	SCICOM SSGHIE
3. The WGEIM recommends that ToR c for 2012 (Fouling hazards and integrated pest management strategies) be developed in more detail with respect to i) therapeutant release, ii) waste management, and iii) propagule pressure within the context of a risk assessment framework. See ToR d for WGEIM 2013.	SCICOM WGEIM
4. The WGEIM recommends that issues relating to multi-trophic aquaculture remain an active EG theme to address issues raised in the current document (ToR d). This includes (but is not limited to) issues relating to ocean ranching of echinoderms (see proposed WGEIM ToR e).	SCICOM
5. The WGEIM recommends that ToR e (seed stock quality) be terminated for the time being. It is felt that the issue has been addressed as far as possible for the time being.	SCICOM WGEIM
6. The WGEIM recommends that future work on fouling in mariculture focus on the environmental effects of pest management with an emphasis on i) therapeutant release, ii) waste management, and iii) propagule pressure. Ultimately, a risk assessment framework will be developed with respect to treatments for pests within a greater pest management framework. Treatment of fish lice and tunicates will serve as case studies.	SCICOM WGEIM
7. The WGEIM recommends that other active ToRs be suspended so as to refocus future efforts based on the outcomes of discussions on the proposed management structure for a new EG on sustainability in aquaculture. Proposed ToRs for 2013 will be re-evaluated at the 2012 ASC.	SCICOM WGEIM WGMASC
8. The WGEIM suggests that a new EG on sustainability in aquaculture be established by the merging of the current WGEIM and WGMASC with an initial meeting of the new EG to occur at the 2012 ASC in Bergen. New ToR will be developed based on current planned ToRs within the WGEIM and WGMASC and based on results from a survey developed by the two EGs and a letter for member countries to solicit requests for subjects. Other options for a new EG structure (see Annex 5) are also possible.	SCICOM WGEIM WGMASC