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Report of the Working Group on Aquaculture (WGAQUA)

16–20 March 2015

Narragansett, USA

International Council for the Exploration of the Sea

Conseil International pour l'Exploration de la Mer

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Executive summary

The ICES Working Group on Aquaculture (WGAQUA), chaired by Peter Cranford (Canada), Pauline Kamermans (Netherlands), and Karin Boxespen (Norway) held its third meeting at the Narragansett Bay Campus of the University of Rhode Island (USA) on 16–20 March 2015 and was attended by 19 members and three guests. Pauline Kamermans had to cancel attendance at short notice for family reasons.

The ICES response to the special advisory request from OSPAR (OSPAR 4/2014 Interactions between wild and captive fish stocks) was the first formal advisory process for WGAQUA. WGAQUA noted large inconsistencies in the science advice developed by WGAQUA and the advice provided by ACOM to OSPAR. WGAQUA subsequently recommended and suggest a more integrated and transparent Advisory process that better promotes the establishment of an ICES science consensus on aquaculture issues and increases transparency, efficiency and confidence in the advice provided to clients.

A synthesis was prepared of reports by ICES SGs and WGs related to sustainable aquaculture on the environmental dependence and effects of aquaculture. This activity clearly demonstrates that ICES has been highly active over the last decade in reviewing the state of knowledge on the environmental dependence and effects of aquaculture and in the provision of advice and recommendations related to the integrated management of sustainable aquaculture (e.g. performance indicator selection, risk assessment approaches, generic and specific management frameworks). The review was helpful in identifying aquaculture issues that have not yet received adequate attention from ICES. It was observed that the present expertise of WGAQUA does not cover all topics that were identified (Product quality, Consumer Safety & Health, Aquatic Animal Health & Welfare).

Evaluating tools for monitoring changes in marine benthic habitats associated with aquaculture is seen as an important area of advice that requires further refinement and development within a new cycle in order to direct scientific recommendations to improve our ability to establish environmental monitoring programs using appropriate tools to assess the impacts of mariculture in non-traditional ecosystems. State-of-the-art sampling methodologies and tools need to be established for the different habitats types, which should be adopted into an international standard that could be utilised as a platform by ICES member countries and other countries globally to establishing monitor programs in substrate types not reflective of soft sediments.

In order to develop an evidence based protocol for the evaluation of the environmental effects of pest management WGAQUA recommends the use of a formalized risk analysis approach. Several protocols exist for estimating environmental risks arising from aquaculture (developed by NOAA, or FAO, or GESAMP, or Fisheries and Oceans Canada). Risk analysis is a decision support tool which focuses management efforts on mitigating potential environmental effects.

Attraction and repulsion of wild populations by finfish and shellfish farms was reviewed. Fish and shellfish farms can attract wild fish, marine mammals, and birds through the addition of food (for fish) to the environment and through the addition of physical structure (farm infrastructure as well as the shellstock that is being grown).

Husbandry activities may also attract fishes and other wild populations. At the same time, husbandry operations and the addition of feed and structure may repel some species through various mechanisms. Studies also indicate that fish farms may influence the reproduction of wild fish.

Ecosystem services associated with aquaculture were categorized by examining the interactions of aquaculture and the environment in the context of the ecosystem where these systems exist. The United Nations Millennium Ecosystem Assessment developed a scheme to categorize the benefits of ecosystems. The four categories of benefits include: provisioning, regulating, cultural, and supporting services. Examples for all four categories were provided. In addition, methods for valuating services were described.

1 Administrative details

Working Group name
Working Group on Aquaculture
Year of Appointment
2013
Reporting year concluding the current three-year cycle
3
Chair(s)
Karin Boxaspen, Norway
Peter Cranford, Canada
Pauline Kamermans, the Netherlands
Meeting venue(s) and dates
18–22 March 2013, Palavas, France, (25 participants)
31 March–4 April 2014, Vigo, Spain, (27 participants)
16–20 March, 2015, Narragansett, USA, (22 participants)

2 Terms of Reference a) – z)

ToR a. Synthesise reports and recommendations by WGAGFM, WGPDMO, WGH-ABD, and WGECO on the environmental dependence and effects of aquaculture (not worked on in 2014)

ToR b. Synthesise previous science advice provided by ICES SGs and WGs related to sustainable aquaculture (not worked on in 2014)

ToR c. Identify emerging aquaculture issues and related science advisory needs for maintaining the sustainability of living marine resources and the protection of the marine environment. The task is to highlight new and important issues that may require additional attention by the WGAQUA and/or another Expert Group as opposed to providing a comprehensive analysis (group exercise)

ToR d. Identify and assess approaches for analysing the effects of aquaculture on benthic habitats with a focus on rocky and mixed substrata bottoms. Recommend approaches to assess/monitor these habitats (Raymond Bannister)

ToR e. Identify and assess approaches for analysing the interactions between aquaculture and eelgrass and maerl beds. Recommend approaches to assess/monitor these habitats (Pauline Kamermans)

ToR f. Analyse and assess the environmental effects of biofouling pest management in aquaculture with an emphasis on i) chemical release, ii) benthic organic enrichment, iii) waste management, and iv) propagule pressure. Ultimately, a risk assessment framework will be developed with respect to treatments for bivalve aquaculture pests within a greater pest management framework (Thomas Landry)

ToR g. Analyse and assess the environmental effects of sea lice pest management in aquaculture with an emphasis on i) therapeutant release, ii) waste management, and iii) propagule pressure (Dave Jackson)

ToR h. Assess and analyse issues relating to the attraction and repulsion of wild populations by fish and shellfish farms and of the impact of this on these populations and the individuals (Chris McKindsey)

ToR i. Analyse and assess the potential ecosystem services and impacts of aquaculture, including extractive aquaculture approaches for environmental impact biomitigation (Myriam Callier)

ToR j. Assess the knowledge base on acceptance of aquaculture in Marine Protected Areas (Adele Boyd)

ToR k. Characterize risks, real and perceived, and potential ecological benefits associated with introducing foreign strains and species of finfish and shellfish and other invertebrates for aquaculture purposes (Gef Flimlin)

ToR l. OSPAR 4/2014 Request Interactions between wild and captive fish stocks (2014 only, Peter Cranford)

3 Summary of Work plan

Year 1	Organize the work of WGAQUA and possibly propose new EGs. Discuss chairs for WGAQUA and possible new EGs. Develop workplan for ToRs depending on attendance (number of people and their expertise). Evaluate Outreach/PR activities and develop outreach plan for Year 2.
Year 2	ToR leaders prepared an outline of each ToR report (potential publication) intersessionally and presented that at the meeting. WGAQUA members worked on ToRs c-l during the meeting. Outreach/PR activities were evaluated and an outreach plan for Year 3 was developed.
Year 3	Finalise products depending on attendance (number of people and their expertise). Discuss future of group.

4 Summary of Achievements of the WG during 3-year term

- A synthesis was prepared of reports and recommendations by SGSA, WGAGFM, WGEIM, WGICZM, WGITMO, WGMASC, and WGPDMO on the environmental dependence and effects of aquaculture and on science advice provided by ICES SGs and WGs related to sustainable aquaculture. This activity clearly demonstrates that ICES has been highly active over the last decade in reviewing the state of knowledge on the environmental dependence and effects of aquaculture and in the provision of advice and recommendations related to the integrated management of sustainable aquaculture (e.g. performance indicator selection, risk assessment approaches, monitoring programs, generic and specific management frameworks, strengthening stakeholder inclusion in decision making …). The review of past activities will strengthen linkages between the WGAQUA and other expert groups and was helpful in identifying aquaculture issues that have not yet received adequate attention from ICES.

- Various suggested emerging topics were compared to the reports, recommendations and advice of earlier groups and there is a relative large overlap. This signifies that some of the topics while maybe not new or emerging they still stand as unresolved and central. The topics relevant for WGAQUA were separated from topics more thematically suited for other groups of ICES. It was observed that the present expertise of WGAQUA does not cover all topics that were identified. E.g. we lack expertise on Product quality, Consumer Safety & Health, Aquatic Animal Health & Welfare. It should be noted that WGAQUA covers a wide range of subjects. Compared to EGs dealing with fish issues there is much less specialisation. Only WGAGFM (genetics), WGPDMO (disease), SGSA (socio-economics) deal with specific aspects of aquaculture. Aquaculture production takes up 40% of the global seafood production. However, this is not reflected in the number EGs working on aquaculture topics.
- A Theme Session for the Annual Science Conference in 2014 was developed. Title: The application of science for ecosystem-based management of aquaculture. Conveners: Dave Jackson (Ireland), Henrik Hareide (Norway), Heather Moore/Adele Boyd (UK), Neil Auchterlonie (UK). While the session drew many excellent presentations, and was therefore considered a success by WGAQUA, attendance at this conference session was judged to be meagre and could be improved in the future by increasing the presence of aquaculture sessions in conference advertising materials. Advertising should also attempt to better target aquaculture regulatory authorities, policy makers and other stakeholders. Carrie Byron introduced the upcoming aquaculture session at ASC 2015 in Copenhagen (Theme Session K: Sustainable approaches to aquaculture in the context of environmental change). The session convenors, Carrie J. Byron (USA) and Gesche Krause (Germany) are soliciting the participation of a third convenor.
- The ICES Aquaculture Dialogue meeting is scheduled for Bergen, Norway on 1-2 June 2015. This meeting with aquaculture stakeholders from ICES member states will discuss areas where science and advice are needed to support sustainable aquaculture. The objective of this meeting is to clearly identify how the ICES science and advisory system can be used to support sustainable aquaculture development. Of particular interest to WGAQUA, this venue will serve as an opportunity to discuss the ICES advisory process as it relates specifically to addressing aquaculture issues. The WGAQUA believes that this discussion is critical to assure the quality, transparency, and legitimacy in aquaculture advice so that users and stakeholders have confidence. At the time of this meeting, the Aquaculture Dialogue agenda includes presentations from

two WGAQUA chairs (P. Kamermans and P. Cranford) that will focus on our science and advisory capacities and possible needs for additional expertise.

- Four manuscripts are being prepared for submission to peer reviewed journals: (1) Evaluating tools for monitoring changes in marine benthic habitats associated with aquaculture, (2) Environmental effects of sea lice pest management in aquaculture (3) Attraction and repulsion of wild populations by finfish and shellfish farms and (4) Ecosystem services associated with aquaculture.

5 Final report on ToRs, workplan and Science Implementation Plan

The ICES response to the special advisory request from OSPAR (OSPAR 4/2014 Interactions between wild and captive fish stocks) was the first formal advisory process for WGAQUA, the out-come and lessons learned became a major topic of discussion at the 2015 annual meeting (**see Annex 6**). WGAQUA noted large inconsistencies in the science advice developed by WGAQUA and the advice provided by ACOM to OSPAR. WGAQUA subsequently recommended and suggest a more integrated and transparent Advisory process that better promotes the establishment of an ICES science consensus on aquaculture issues and increases transparency, efficiency and confidence in the advice provided to clients.

ICES currently holds liaison A status with ISO Technical Committee 234 (Fisheries and Aquaculture). For detailed progress on that topic **see Annex 7**. In response to an ongoing request from ISO for ICES to provide input on the possible development of new standards. In addition, WGAQUA recommends that ICES nominate a member to a newly proposed ISO (International Organization for Standardization) working group (ISO/NP 18860) entitled "Terminology and formulas describing conversion of marine raw materials (fish oil and fishmeal) into aquaculture output".

The work on ToR a and ToR b were conducted and reported simultaneously by reviewing the contents of past ICES expert group reports to extract and synthesize information that was relevant to the WGAQUA 3-year work plan (**see Annex 8**). Annual reports generated between 2003 and 2014 by the SGSA/WGSEDA, WGAGFM, WGPDMO, WGICZM/WGMPCZM, WGITMO, WGEIM (last year was 2012) and WGMASC (last year was 2012) were screened to identify and summarize topics addressed related to the environmental dependence and effects of aquaculture (ToR a), and advise and recommendations related to sustainable aquaculture (ToR b).

The purpose of ToR c is to highlight new and important issues that may require additional attention by the WGAQUA and/or another Expert Group as opposed to providing a comprehensive analysis. During the meeting a scoping exercise was conducted to further refine aquaculture issues and to identify issues that could be better addressed by other EGs (**see Annex 9**). The main issues identified in 2015, in no particular order, were:

- Effectiveness of open-water Integrated Multi-Trophic Aquaculture (IMTA) operations to recycle and extract particulate and dissolved wastes generated by fish culture.
- Feasibility of closed containment systems as an alternative to open-water net-pen fish culture.

- Ecosystem interactions and health and welfare issues associated with the use of alternatives to traditional fish feed components (e.g. terrestrial plants and insects, shellfish, ascidians, microbes, seaweed, etc.)
- Potential role of aquaculture in establishing food security.
- How to define an acceptable impact level and spatial zone (i.e. what is a "sustainable" aquaculture operation). What are appropriate ecological carrying capacity thresholds? These answers require the development of management frameworks and systems that integrate science and socio-economic considerations.
- Is ocean acidification presently impacting aquaculture production in the ICES area?

Over the three-year cycle to address the 11 original ToRs of WGAQUA, many ToRs became merged under common aquaculture theme areas (Table 1). This ToR grouping and reporting was done to limit the considerable overlap in subject areas and to account for the changing participation of many experts over the reporting cycle.

Table 1. Distribution of WGAQUA ToRs into three primary work themes.

ToRs	Theme	Leader	Participants (2013–2015)
d. Effects of aquaculture on benthic habitats with a focus on rocky and mixed substrata bottoms.	I	Raymond Bannister	Corina Busby, Francis O'Beirn, Else Marie Djupevag, Ingrid Burgetz, Montse Pérez
e. Interactions between aquaculture and eelgrass and maerl beds.	I	Pauline Kamermans	
j. Acceptance of aquaculture in Marine Protected Areas.	I	Adele Boyd	
f. Environmental effects of biofouling pest management in aquaculture.	II	Thomas Landry	Karin Boxaspen, Knud Simonsen, Camino Gestal, Henrik Hareide, Olav Moberg
g. Environmental effects of sea lice pest management in aquaculture.	II	Dave Jackson	
k. Introducing foreign strains and species of finfish and shellfish and other invertebrates for aquaculture purposes.	II	Gef Flimlin	
l. Special request: Interactions between wild and captive fish stocks (OSPAR 4/2014).	III	Peter Cranford	David Bengtson, Ulfert Focken, Jose Iglesias, Heather Moore, Terje Svasand, Carmen Gonzalez, Ulrich Knaus, Oivind Strand, Stephen Cross, Wojciech Wawrzynski, Kristina Sundell, Gary Wikfors Bob Rheault
h. Attraction and repulsion of wild populations by fish and shellfish farms.	III	Chris McKindsey	
i. Potential ecosystem services and impacts of aquaculture.	III	Myriam Callier	

It was agreed that WGAQUA would continue to work in three sub-groups that target the ToR themes identified in Table 1. In brief:

i. ToRs d, e and j were merged into "Assessing and developing tools for monitoring changes in marine benthic habitats associated with aquaculture in the North Atlantic area" led by theme leader Raymond Banester (Norway), **see Annex 10**,

ii. ToRs f, g, and k were all placed under the umbrella of "Aquaculture Pest Management", led by Dave Jackson (Ireland), **see Annex 11** and

iii. ToRs h and i were grouped to address the WGAQUA theme of "Ecosystem Interactions with aquaculture", which was led by Chris McKindsey. Work under this theme also fed into the OSPAR advisory request (ToR l) **see Annex 12**.

Preliminary discussions were scheduled to determine how to report on individual ToRs led by members that were not able to be present at the 2015 meeting (ToRs e, f, k, and i).

Evaluating tools for monitoring changes in marine benthic habitats associated with aquaculture (**ToRs d, e and j in Annex 10**) indicates that environmental pressure from mariculture activities will and have been shifting from habitats dominated by soft sediment substrates to habitats with heterogeneous mixed and hard bottom substrate types. These substrate types contain different habitats, such as, rocky reefs, macroalgal communities (i.e. Kelp forests and other seaweeds), as well as biogenic features (seagrasses, mearl beds, saltmarshes, carbonate sandy sediments, sponge gardens, cold-water coral reefs, mussel beds). Drivers of ecological impacts, habitat sensitivity, and current environmental monitoring of benthic environmental changes associated with mariculture were reviewed as well as lessons to learn from soft sediments to apply to new habitats. This ToR is seen as an important area of advice that requires further refinement and development within a new cycle in order to direct scientific recommendations to improve our ability to establish environmental monitoring programs using appropriate tools to assess the impacts of mariculture in non-traditional ecosystems. State-of-the-art sampling methodologies and tools require further identification, scientific refinement, and an evaluation of practicality and cost-benefit for implementation into national surveying protocols. These tools/methodologies need to be established for the different habitats types, which should be adopted into an international standard that could be utilised as a platform by ICES member countries and other countries globally to establishing monitor programs in substrate types not reflective of soft sediments.

In order to develop an evidence based protocol for the evaluation of the environmental effects of sea lice pest management WGAQUA has assessed the current state of the art in Risk Analysis and the state of knowledge in respect of the relevant scientific data (**ToR g in Annex 11**). The aquaculture industry and its regulators must make decisions which could potentially have major consequences based on incomplete knowledge and with varying degrees of uncertainty. This can only be achieved in a structured way by the use of a formalized risk analysis approach. Use of risk analysis in aquaculture development and management is relatively new. Nevertheless, several protocols exist for estimating environmental risks arising from aquaculture. NOAA developed guidelines for ecological risk assessment of marine fish aquaculture in 2005. This work was further developed by FAO who presented broader guidelines for understanding and applying risk analysis in aquaculture in 2008. The same year GESAMP provided guidelines on environmental risk assessment and communication in coastal aquaculture. Fisheries and Oceans Canada has developed and is implementing an aquaculture science environmental risk assessment framework. Risk analysis is a decision support tool which focuses management efforts on mitigating potential environmental effects.

Attraction and repulsion of wild populations by finfish and shellfish farms was reviewed (**ToR h in Annex 12**). Fish and shellfish farms can attract wild fish, marine mammals, and birds through the addition of food (for fish) to the environment and through the addition of physical structure (farm infrastructure as well as the shellstock that is being grown). Husbandry activities may also attract fishes and other wild populations. At the same time, husbandry operations and the addition of feed and structure may repel some species through various mechanisms. Studies also indicate that fish farms may influence the reproduction of wild fish.

Ecosystem services associated with aquaculture were categorized by examining the interactions of aquaculture and the environment in the context of the ecosystem where these systems exist (**ToR i in Annex 12**). The United Nations Millennium Ecosystem Assessment developed a scheme to categorize the benefits of ecosystems. The four categories of benefits include: provisioning, regulating, cultural, and supporting services. Examples for all four categories were provided. In addition, methods for valuating services were described.

6 Cooperation

- **Cooperation with other WG**

WGAQUA reviewed the contents of past ICES expert group reports to extract and synthesize information that is relevant to the WGAQUA workplan. This exercise was also conducted to avoid overlap between expert group activities, to assist in linking topics of common interest, to integrate work products, and to communicate outputs across ICES expert groups.

In 2014, a member of WGAQUA attended the SGSA meeting in Maine.

- **Cooperation with Advisory structures**

In 2014, WGAQUA responded to the special advisory request from OSPAR (OSPAR 4/2014 Interactions between wild and captive fish stocks) (see Annex 6).

- **Cooperation with other IGOs**

ICES holds liaison A status with ISO Technical Committee 234 (Fisheries and Aquaculture). The Science Advice Chair monitors the ISO balletting process to inform the ICES secretariat of any aquaculture activities that require attention. WGAQUA has agreed to participate in a newly proposed ISO theme (ISO/NP 18860) entitled ``Terminology and formulas describing conversion of marine raw materials (fish oil and fishmeal) into aquaculture output``. In response to an ongoing request from ISO WGAQUA provided input on the possible development of new standards.

7 Summary of Working Group evaluation and conclusions

WGAQUA contribution to research priorities (RP):

The ToRs of WGAQUA focus on impacts from aquaculture, e.g. effects of aquaculture on benthic habitats, environmental effects of biofouling and pest management, attraction and repulsion of wild populations by fish and shellfish farms and introducing foreign strains and species of finfish and shellfish and other invertebrates for aquaculture. Thus, they contribute to RP 11, 13, 16 and 17. Work on these ToRs include reviewing the state-of-the-art concerning tools for monitoring effects of aquaculture. This contributes to RP 25, 26, 27 and 28. And aquaculture related risk assessments, contributing to RP 23. Furthermore, our ToR on acceptance of aquaculture in Marine Protected Areas contributes to RP 23 as well. And finally, potential ecosystem services and of structural and functional diversity aquaculture (e.g. IMTA) are reviewed, which contributes to RP 5, 8, 9. IMTA also serves as a mitigation of aquaculture, contributing to RP 12.

Research Priorities (RP):

5. Quantify the role of structural and functional diversity in marine ecosystems in providing stability and resilience
8. Define and quantify north Atlantic Ecosystem Goods and Services, model their dependence on ecosystem processes and habitat condition and their social, economic and cultural value.
9. Identify indicators of ecosystem state and function for use in the assessment and management of ecosystem goods and services
11. Develop methods to quantify multiple direct and indirect impacts from fisheries as well as from mineral extraction, energy generation, aquaculture and other anthroponegic activities and estimate the vulnerability of ecosystems to such impacts.
12. Develop approaches to mitigate impacts from these activities, particularly reduction of non-target mortalities and enhancement/restoration of habitat and assess the effects of these mitigations on marine populations
13. Develop indicators of pressure on populations and ecosystems from human activities such as eutrophication, contaminants and litter release, introduction of alien species and generation of underwater noise.
16. Quantify and map biological, ecological and environmental values with an aim to optimize ecosystem use and minimize environmental impacts in relation to ecosystem carrying capacity
17. Develop science in support of advisory needs in marine aquaculture systems, minimizing environmental impacts and integrating other marine sectors.
23. Use IEA's to in informing management about the effects of cumulative pressure and additive and non-additive impacts, and which provide risk evaluations and analyses of trade-offs between sectoral objectives.
25. Identify monitoring requirements for science and advisory needs in collaboration with data product users, including a description of variable and data products, spatial and temporal resolution needs, and the desired quality of data and estimates
26. Develop a cost benefit framework to evaluate and optimize monitoring strategies in the context of the capabilities of, and requests from ICES Member Countries and clients.

27. Identify knowledge and methodological monitoring gaps and develop strategies to fill these gaps
28. Promote new technologies and opportunities for observation and monitoring and assess their capabilities in the ICES context

Advisory products:

- OSPAR 4/2014 response: Interactions Between Wild and Captive Fish Stocks. (WGAQUA Interim Report, 2014). A major conclusion was that "aquaculture activities in the ICES and OSPAR regions are highly diverse and impacts on wild fish may be expected to be highly site-specific. Consequently, it was not possible for WGAQUA to reach generic conclusions on aquaculture (shellfish and fin-fish) interactions with wild fish, or to identify and prioritize major mariculture pressures that are applicable across the full ICES or OSPAR regions".
- In response to an ongoing request from ISO for ICES WGAQUA provided input on the possible development of new standards.

Outreach activities:

- The Science Advice Chair of WGAQUA attended the Workshop on Ecosystem Approach to Aquaculture (EAA) of the Aquaculture sub-working group of the Trans-Atlantic Ocean Research Alliance between the US, Canada and the EU as a follow-up of the Galway Declaration.

Difficulties:

- Not all ToRs require a 3-year cycle and others require more time. The currently long reporting cycle has a high potential to delay many EG work outcomes by up to 2 years and preventing any reporting on work that was not completed in the final year.

Future plans:

- Continuation of the WG beyond its current term.
- Additional expertise that would improve the ability of the WG to fulfil its ToR is Product quality; Consumer Safety & Health; Aquatic Animal Health & Welfare, Aquaculture Socio-economics; aquaculture species responses to ocean acidification.
- WGAQUA recommends a more integrated and transparent Advisory process that better promotes the establishment of an ICES science consensus on aquaculture issues. A modified Advisory process was suggested by WGAQUA to increase coordination and communication between participating EGs, ACOM and the client. Such a process would increase transparency, efficiency and confidence in the advice provided to clients.

Annex 1: List of participants

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Annex 2: Agenda

Coastal Institute building at the Narragansett Bay Campus of the University of Rhode Island, 220 South Ferry Road, Narragansett, RI, USA

Monday 16 March

08:30	Welcome from Dean Bruce Corliss and house-keeping information from David Bengtson
	Introductory round and adoption of the agenda
	Introduction to ICES Science Work by Peter Cranford (including Annual Science Conference)
	Introduction to ICES Advisory Work by Peter Cranford (including ISO and the Aquaculture Dialogue Meeting in June in Norway)
10:30	*Health Break*
11:00	Plenary to discuss Terms of Reference (ToRs) (presentations of ToR leaders, identify subgroups)
	d. Effects of aquaculture on benthic habitats with a focus on rocky and mixed substrata bottoms (Raymond Bannister)
	e. Interactions between aquaculture and eelgrass and maerl beds (Pauline Kamermans)
	j. Acceptance of aquaculture in Marine Protected Areas (Adele Boyd)
12:00	**Lunch (at Nautilus Cafe at the Bay Campus, own costs)**
13:00	Plenary to discuss Terms of Reference (ToRs) continued
	f. Environmental effects of biofouling pest management in aquaculture (Thomas Landry)
	g. Environmental effects of sea lice pest management in aquaculture (Dave Jackson)
13:40	**h.** Attraction and repulsion of wild populations by fish and shellfish farms (Chris Mckindsey)
	i. Potential ecosystem services and impacts of aquaculture (Myriam Callier)
	k. Introducing foreign strains and species of finfish and shellfish and other invertebrates for aquaculture purposes (Thomas Landry)
14:40	**a.** Recommendations by ICES SGs and WGs on the environmental dependence and effects of aquaculture (Pauline Kamermans)
	b. Science advice provided by ICES SGs and WGs related to sustainable aquaculture (Peter Cranford)
	c. Emerging aquaculture issues (separate time slot on Thursday)
15:00	*Health Break*
15:30	Split up in subgroups to develop work plan for remainder of meeting (identify rapporteurs)
17:30	End of day 1
	Dinner on your own

Tuesday 17 March

08:30	Evaluation Advisory Work and preparation Aquaculture Dialogue Meeting (including recommendations) (Peter Cranford)
10:00	AORAC project, Atlantic Ocean Research Alliance Coordination and Support Action (Wojciech Wawrzynski)
10:30	*Health Break*
11:00	Reconvene ToR subgroup sessions
12:00	**Lunch (at Nautilus Cafe at the Bay Campus, own costs)**
13:00	Continue ToR subgroup sessions
15:00	*Health Break*
15:30	Continue ToR subgroup sessions
17:30	End of day 2
	Dinner on your own

Wednesday 18 March

08:30	Tour of the aquaculture research facilities at the Narragansett Bay Campus and visit Matunuck Oyster Farm
12:00	**Lunch at the Matunuck Oyster Bar**
13:00	Reconvene ToR subgroup sessions
15:00	*Health Break*
15:30	Reconvene ToR subgroup sessions
17.30	End of day 3
	Dinner on your own

Thursday 19 March

08:30	ToR c. Identify emerging aquaculture issues and related science advisory needs for maintaining the sustainability of living marine resources and the protection of the marine environment (Karin Boxaspen).
10:30	*Health Break*
11:00	Plenary session to outline progress (3 subgroups plus science advice ToR)
12:00	**Lunch (at Nautilus Cafe at the Bay Campus, own costs)**
13:00	Continue ToR subgroup sessions to finish document with main conclusions
15:00	*Health Break*
15:30	Continue ToR subgroup sessions to finish document with main conclusions
17:30	End of day 4
	Dinner with the whole group (40 dollars per person)

Friday 20 March

08:30	Plenary to draft recommendations
10:30	*Health Break*
11:00	Plenary to draft new Terms of Reference
12:00	**Lunch**
13:00	Plenary discussion on new chairs and date and location of the next meeting
14.00	Plenary to discuss self-evaluation
15:00	All documents to chair before End of day 5

Annex 3: Recommendations

Recommendation	Adressed to
1. Large inconcistencies in the science advice developed by WGAQUA in 2014 and the advice provided by ACOM to OSPAR reveal the need for a more integrated aquaculture advisory process that promotes the establishment of an ICES science consensus. WGAQUA recommends that ACOM adopt a revised process, including suggestions by WGAQUA, that is specifically designed to address aquaculture issues. The suggested process would increase coordination and communication between participating EGs, ACOM and the client on aquaculture questions. Such a process would increase transparency, efficiency and confidence in the advice provided to clients.	ICES Secretariat, ACOM, SCICOM, SSGEPI
2. WGAQUA recommends a continuation of the WG beyond its current term with the group being chaired by Dave Jackson (Ireland), Myriam Callier (France) and Ole Torreson (Norway).	SSGEPI
3. WGAQUA proposes the establishment of a study group (Expert Group on Aquaculture Constraints) to address a ToR that assembles available knowledge on the technological and ecological barriers limiting the future growth of sustainable mariculture. This EG would also examine the capacity of new mariculture technologies (e.g. integrated multi-trophic aquaculture, and closed containment) to enhance food security and parisite control while reducing environmental risks. It is recommended that this group hold contiguous annual meetings with, and report to WGAQUA, with the goal of identifying priority reseach topics that would help alleviate constraints on industry growth.	SSGEPI
4. WGAQUA recommends extending ToRd (Identify and assess approaches for analysing the effects of aquaculture on benthic habitats with a focus on rocky and mixed substrata bottoms) and ToR e (Identify and assess approaches for analysing the interactions between aquaculture and eelgrass and maerl beds) into the next work cycle under a combined ToR (Assessing and developing tools for monitoring changes in marine benthic habitats associated with aquaculture in the North Atlantic area) . Extending these ToRs will refine and improve the present knowledge base towards developing a primary pubication.	SSGEPI
5. WGAQUA recommends establishing a new ToR in 2016 to review and report on the state of knowledge on ecosystem interactions and health and welfare issues associated with the use of alternatives to traditional fish feed components (e.g. terrestrial plants and insects, shellfish, ascidians, microbes , seaweed, etc.). The objective is to prepare a review of the available literature that identifies gaps in knowledge and associated research priorities. This recommendation necessitates the identification and solicitation of additional experts to join WGAQUA to work on this ToR.	SSGEPI
6. WGAQUA recommends establishing a new ToR, starting in 2016, to collate, analyze and compare the various environmental monitoring approaches used in ICES member states to address the sustainability status of marine aquaculture activities. The goals are to determine the specific objectives of each monitoring program (environmental and social), to compare how decisions are made based on monitoring data, and to ascertain the science-basis and robustness of the monitoring designs and methodologies employed. WGAQUA recommends that the Socio-Economic Dimensions of Aquaculture working group (WGSEDA) hold an overlapping	SSGEPI, WGSEDA

meeting with WGAQUA (2017 or 2018) to facilitate collaboration in addressing this ToR.	
7. WGAQUA recommends establishing a new ToR, starting in 2016, to review and report on the current status and risks of aquaculture impacts from ocean acidification. This recommendation necessitates the identification and solicitation of additional experts to join WGAQUA to work on this ToR.	SSGEPI
8. WGAQUA recommends that ICES nominate a member to a newly proposed ISO (International Organization for Standardization) working group (ISO/NP 18860) entitled "Terminology and formulas describing conversion of marine raw materials (fish oil and fishmeal) into aquaculture output". David Bengtson volunteered to have his name put forward to participate in this ISO exercise. The deadline for submitting the ICES response via ISO balloting is 16 April, 2015. A list of potential new standards for ISO is provided and WGAQUA recommends that the list be sent to ISO.	ICES secretariat

Annex 4: WGAQUA draft multi-annual resolution

The **Working Group on Aquaculture** (WGAQUA), chaired by Dave Jackson (Ireland), Myriam Callier (France) and Ole Torreson (Norway), will meet in Yerseke, The Netherlands, 4-8 April, 2016 to on ToRs and generate deliverables as listed in the Table below.:

WGAQUA will report by 29 April 2016 for the attention of the SSGEPI.

ToR descriptors

ToR	Description	Background	Science Plan priorities addressed	Duration	Expected Deliverables
a	Continue previous work on the identification and assessment of tools for monitoring changes in rocky and mixed substrata marine benthic habitats, including eelgrass and maerl beds, associated with aquaculture in the ICES area. Expand to include considerations of scientifically defensible temporal and spatial scales of aquaculture impacts relevant to the management of habitat protection.	Development and establishment of monitoring methodology/tools for detecting/evaluating environmental impacts of aquaculture to marine ecosystems has been a topic of interest for traditional cultivation locations over the past two decades. However, most of this work has concentrated on soft substratum habitats. The gradual relocation of aquaculture facilities to deeper localities dominated by hard and mixed substrata habitats has resulted in problems with using established monitoring tools. Therefore, there is an urgent need to establish standardized monitoring methodology/tools for hard bottom and/or mixed bottom habitats. Resolving the ecological significance and effect on fisheries from different scales of benthic impacts, including effects on critical habitat, is important to the development of management measures. These subjects would benefit from a review of science progress and an evaluation of the results obtained.	11,13,16,17, 25,26,27,28	2.3	ICES EG report and, when possible, publish outputs in peer review literature
b	Review and report on the state of knowledge on ecosystem interactions and health and welfare issues associated with the use of alternatives to traditional fish feed components (e.g. terrestrial plants and insects, shell-fish, ascidians, microbes , seaweed, etc.).	In an attempt to reduce dependence on wild fisheries as a food source for cultured fish, the aquaculture industry is exploring the use of multiple alternative sources of feed components, many of which are from non-marine sources. An information gap exists on how feed waste (e.g. atypical fatty acid components in fish faeces) interacts with the marine food web. An analysis of this emerging issue is needed to establish the ecological risks and health and welfare issues associated with the introduction of unnatural food	11,12,13,16, 17	3	ICES EG report and, when possible, publish outputs in peer review literature

		chains to marine waters via the use of engineered feed formulations.			
c	Collate, analyze and assess the various environmental monitoring approaches used in ICES member states to address the sustainability status (environmental effects and impacts) of marine aquaculture activities (fish and shellfish). Ascertain the specific objectives of the different monitoring programs (environmental and social), and identify how regulatory decisions are made based on ongoing monitoring data and established performance thresholds.	Environmental monitoring is a critical step in an aquaculture management framework and the present state of monitoring provides information on regional governance responses to the ecological and societal pressures that limit industry growth. An analysis of current monitoring practices used by ICES member states would help to reveal geographic trends in environmental concerns related to local aquaculture activities, would indicate if monitoring objectives are consistent, and would help to identify any commonality in the setting of regulatory thresholds for managing environmental status and impacts. Identifying a set of common thresholds through an examination of present practices is insightful because it is difficult for scientists alone to provide advice on what is an "acceptable impact". This knowledge would benefit future response to requests for science advice.	11,13,16,17, 25,26,27,28	3	ICES EG report and, when possible, publish outputs in peer review literature
d	Review and report on the current status of aquaculture impacts from ocean acidification and identify major risks.	The potential impacts on aquaculture, particularly for shellfish, from ocean acidification have been widely reported in the popular press. An analysis of the present reality and future risks from acidification is needed to separate science from hype. An analysis of available science information would identify the risks, life-stage sensitivities, stock resistence and adaptation, and potential mitigation measures.	1,3,4,23	3	ICES EG report and, when possible, publish outputs in peer review literature
e	Identify emerging aquaculture issues and related science advisory needs for maintaining the sustainability of living marine resources and the protection of the marine environment. The task is to highlight new and important issues that may require additional attention by the WGAQUA and/or another Expert Group as opposed to providing a comprehensive	For WGAQUA to effectively address relevant issues and provide timely science advice to promote the sustainable use of living marine resources and the protection of the marine environment, it must first flag emerging issues identified by the various participants. This activity will identify and rank issues identified by the group as a whole that may require future attention by the WGAQUA or other related ICES Expert Groups, either alone or through collaborative work. The task is to highlight new and important issues that may require additional attention by the WGAQUA and/or another Expert Group as opposed to providing a comprehensive analysis. Proposals for	1,3,4,5,8,9, 11,12,13,16, 17,23,25,26, 27,28	3	ICES EG reports

analysis.	Theme Sessions for the Annual Science Conference may evolve from this activity.

Summary of the Work Plan

Year 1	Organize the work of WGAQUA and possibly propose new EGs. Discuss chairs for WGAQUA and possible new EGs. Develop workplan for ToRs depending on attendance (number of people and their expertise). Evaluate Outreach/PR activities and develop outreach plan for Year 2.
Year 2	ToR leaders will prepare an outline of each ToR report (potential publication) intersessionally and will present that at the meeting. WGAQUA members will work on ToRs c-k during the meeting depending on attendance (number of people and their expertise). Evaluate Outreach/PR activities and develop outreach plan for Year 3.
Year 3	ToR leaders prepare outline of publication intersessionally and present that at meeting. During meeting finalize products depending on attendance (number of people and their expertise). Discuss future of group.

Supporting information

Priority	The current activities of WGAQUA will lead ICES into issues and advisory needs related to the environmental dependence, effects and ecosystem services of aquaculture. Consequently, these activities are considered to have a high priority.
Resource requirements	Travel for SCICOM leadership to inform clients about advisory capacity of WGAQUA, travel for WGAQUA Science Advice Chair to participate in meetings where questions requiring advice are drafted. The additional resource required to undertake additional activities in the framework of this group is negligible.
Participants	The Group is normally attended by some 20–30 members and guests.
Secretariat facilities	None.
Financial	No financial implications.
Linkages to ACOM and groups under ACOM	ACOM – advice on aquaculture, WGITMO (introduced species)
Linkages to other committees or groups	Coordination and cooperation with WGSEDA is of high importance for WGAQUA and an open invitation is in place for the coordination of meeting time and place . Other groups: WGPDMO, WGBEC, WGAGFM, WGICZM, WGITMO, WGHABD
Linkages to other organizations	European Aquculture Society. See also the Aquaculture Dialogue organized for 1-2 June, 2015

Annex 5: Copy of Working Group evaluation

1) Working Group name: Working Group on Aquaculture
2) Year of appointment: 2013
3) Current Chairs: Peter Cranford (Canada), Pauline Kamermans (The Netherlands), Karin Boxaspen (Norway)
4) Venues, dates and number of participants per meeting:
Palavas (France), 18 to 22 March 2013, 25 participants
Vigo (Spain), 31 March to 4 April 2014, 27 participants
Narragansett, Rhode Island (USA), 16 to 20 March, 2015, 22 participants

WG Evaluation

5) If applicable, please indicate the research priorities (and sub priorities) of the Science Plan to which the WG make a significant contribution.

Science Plan priority	**WGAQUA contribution**
1. Assess the physical, chemical and biological state of regional seas and investigate the predominant climatic, hydrological and biological features and processes that characterise regional ecosystems	effect of climate change on aquaculture, e.g. WGMASC ToR 2008-2012
2. Quantify the nature and degree of connectivity and separation between regional ecosystems	Bivalve aquaculture transfers between sites WGMASC ToR 2008-2012
3. Quantify the different effects of climate change on regional ecosystems and develop species and habitat vulnerability assessments for key species	effect of climate change on aquaculture, e.g. WGMASC ToR 2008-2012
4. Understand the influence of climate impacts across a range of temporal and spatial scales, from local to global and from seasonal to multidecadal and identify indicators of climate driven biotic responses and forecast trajectories of change	effect of climate change on aquaculture, e.g. WGMASC ToR 2008-2012
5. Quantify the role of structural and functional diversity in marine ecosystems in providing stability and resilience	effects of aquaculture on benthic habitats and environmental effects of biofouling pest management, e.g. WGAQUA ToRs (2013-2015)
6. Investigate linear and non-linear ecological responses to change, the impacts of these changes on ecosystem structure and function and their role in causing recruitment and stock variability, depletion and recovery.	effect of climate change on aquaculture, e.g. WGMASC ToR 2008-2012
7. Develop end to end modelling capability to fully integrate natural and anthropogenic forcing factors affecting ecosystem functioning	carrying capacity modelling, e.g. WGMASC ToR Impacts of shellfish aquaculture activities in the coastal zone (2006-2009)
8. Define and quantify north Atlantic Ecosystem Goods and Services, model their dependence on	Analyse and assess the potential ecosystem services and impacts of aquaculture, attraction and

ecosystem processes and habitat condition and their social, economic and cultural value.	repulsion of wild populations by fish and shellfish farms WGAQUA Tors (2013-2015)
9. Identify indicators of ecosystem state and function for use in the assessment and management of ecosystem goods and services	evaluate indicators, e.g. WGMASC ToR Impacts of shellfish aquaculture activities in the coastal zone (2006-2009)
11. Develop methods to quantify multiple direct and indirect impacts from fisheries as well as from mineral extraction, energy generation, aquaculture and other anthroponegic activities and estimate the vulnerability of ecosystems to such impacts.	impacts from aquaculture, WGAQUA ToRs 2013-2015
12. Develop approaches to mitigate impacts from these activities, particularly reduction of non-target mortalities and enhancement/restoration of habitat and assess the effects of these mitigations on marine populations	Analyse and assess the potential ecosystem services and impacts of aquaculture, attraction and repulsion of wild populations by fish and shellfish farms WGAQUA Tors (2013-2015) IMTA serves as a mitigation of aquaculture.
13. Develop indicators of pressure on populations and ecosystems from human activities such as eutrophication, contaminants and litter release, introduction of alien species and generation of underwater noise.	introducing foreign strains and species of finfish and shellfish and other invertebrates for aquaculture purposes, evaluate indicators, e.g. WGMASC ToR Impacts of shellfish aquaculture activities in the coastal zone (2006-2009) + WGAQUA ToRs 2013-2015
14. Evaluate ecological, economic and social trade-offs between ecosystem protection and sustainable use to advise on management of human activity in marine ecosystems	acceptance of aquaculture in Marine Protected Areas, WGAQUA ToR (2013-2015)
16. Quantify and map biological, ecological and environmental values with an aim to optimize ecosystem use and minimize environmental impacts in relation to ecosystem carrying capacity	carrying capacity modelling, e.g. WGMASC ToR Impacts of shellfish aquaculture activities in the coastal zone (2006-2009), impacts from aquaculture, WGAQUA ToRs 2013-2015
17. Develop science in support of advisory needs in marine aquaculture systems, minimizing environmental impacts and integrating other marine sectors.	all ToRs of WGAQUA
23. Use IEA's to in informing management about the effects of cumulative pressure and additive and non-additive impacts, and which provide risk evaluations and analyses of trade-offs between sectoral objectives.	aquaculture related risk assessments
25. Identify monitoring requirements for science and advisory needs in collaboration with data product users, including a description of variable and data products, spatial and temporal resolution needs, and the desired quality of data and estimates	most WGAQUA ToRs 2013-2015 include recommendations on monitoring

26. Develop a cost benefit framework to evaluate and optimize monitoring strategies in the context of the capabilities of, and requests from ICES Member Countries and clients.	can provide data needed for cost benefit analyses
27. Identify knowledge and methodological monitoring gaps and develop strategies to fill these gaps	most WGAQUA ToRs 2013-2015
28. Promote new technologies and opportunities for observation and monitoring and assess their capabilities in the ICES context	most WGAQUA ToRs 2013-2015

6) In bullet form, list the main outcomes and achievements of the WG since their last evaluation. Outcomes including publications, advisory products, modelling outputs, methodological developments, etc. *

- OSPAR 4/2014 response: Interactions Between Wild and Captive Fish Stocks. (WGAQUA Interim Report, 2014).
- In response to an onging request from ISO for ICES WGAQUA provided input on the possible development of new standards.

7) Has the WG contributed to Advisory needs? If so, please list when, to whom, and what was the essence of the advice.

WGAQUA responded to ACOM in 2014 on an advisory request from OSPAR (4/2014; Interactions between wild and captive fish stocks). The advice was contained in an extensive science review document containing information on the following environmental pressures on wild fisheries from mariculture activities:

- introduction of antibiotics and other pharmaceuticals;
- parasite interactions;
- non-genetic interactions from mass releases of cultured organisms (fish escapes and bivalve transfers/spawning);
- release of nutrients and organic matter;
- addition of structure/habitat by bivalve culture, and
- utilization of trophic resources by mariculture.

A major conclusion was that "aquaculture activities in the ICES and OSPAR regions are highly diverse and impacts on wild fish may be expected to be highly site-specific. Consequently, it was not possible for WGAQUA to reach generic conclusions on aquaculture (shellfish and fin-fish) interactions with wild fish, or to identify and prioritize major mariculture pressures that are applicable across the full ICES or OSPAR regions".

8) Please list any specific outreach activities of the WG outside the ICES network (unless listed in question 6). For example, EC projects directly emanating from the WG discussions, representation of the WG in meetings of outside organizations, contributions to other agencies' activities.

The Science Advice Chair of WGAQUA attended the Workshop on Ecosystem Approach to Aquaculture (EAA) organised in San Sebastian, Spain 14 October 2014. This workshop was the first action by the Aquaculture sub-working group of the Trans-Atlantic Ocean Research Alliance between the US, Canada and the EU as a follow-up of the Galway Declaration. Peter Cranford promoted ICES and WGAQUA as a means of structuring cooperation among the three partners and sharing information on each other's research activities in the field.

9) Please indicate what difficulties, if any, have been encountered in achieving the workplan.

- The expertise of WGAQUA does not cover all aquaculture topics that were identified by ICES prior to formation of the group. For example, WGAQUA lacks expertise on product quality, consumer safety & health, and aquatic animal health & welfare.
- The 3-year cycle puts a major pressure (albeit unintentional) on drafting ToR reports in the final year. The absence of key members during that year prevents completion of ToRs on which they have been leading, or which they were contributing too in a significant manner. This would have previously been remedied by adding an additional year to the ToR. The cycle is also less favourable for conducting a 1-year scoping exercise to assess issues related to potentially recommending a new ToR. Not all ToRs require a 3-year cycle and others require more time. The currently long reporting cycle has a high potential to delay many EG work outcomes by up to 2 years and preventing any reporting on work that was not completed in the final year.

Future plans

10) Does the group think that a continuation of the WG beyond its current term is required? (If yes, please list the reasons)

Yes.

- Goal 1 of the current ICES Strategic Plan strives to develop an integrated, multidisciplinary understanding of marine ecosystems, their resilience and response to change. WGAQUA investigates the environmental dependence and effects of aquaculture through the adoption of an ecosystem approach. This work provides recommended methodologies and tools for assessing aquaculture ecosystem interactions and management/monitoring frameworks.
- Goal 3 of the current ICES Strategic Plan notes the need to evaluate and advise on options for the sustainable use and protection of marine ecosystems. WGAQUA is the focal point in ICES for achieving this goal with respect to aquaculture.

11) If you are not requesting an extension, does the group consider that a new WG is required to further develop the science previously addressed by the existing WG.

No.

12) What additional expertise would improve the ability of the new (or in case of renewal, existing) WG to fulfil its ToR?

Product quality; Consumer Safety & Health; Aquatic Animal Health & Welfare, Aquaculture Socio-economics; aquaculture species responses to ocean acidification.

13) Which conclusions/or knowledge acquired of the WG do you think should be used in the Advisory process, if not already used? (please be specific)

Annex 6 of the 2015 WGAQUA report (Aquaculture Advice: Retrospective Analysis and Recommendations) details the large inconsistencies in the science advice developed by WGAQUA in 2014 and the advice provided by ACOM to OSPAR. Major conclusions and large sections of the science advice provided by WGAQUA were also excluded from the ACOM report to OSPAR and should be included in the Advisory process. WGAQUA subsequently recommended a more integrated and transparent Advisory process that better promotes the establishment of an ICES science consensus on aquaculture issues. A modified Advisory process was suggested by WGAQUA to increase coordination and communication between participating EGs, ACOM and the client. Such a process would increase transparency, efficiency and confidence in the advice provided to clients.

Annex 6: Aquaculture Advice: Retrospective Analysis and Recommendations

ToR L: Request for Advice on Interactions between wild and captive fish stocks (OSPAR 4/2014)

The most sound science advice is provided by experts actively working in that field of research. Science advice on an issue related to aquaculture, or any anthropogenic activity, is of limited value if it has not been solicited by a client that wants to follow it and if the advice provided to that client does not represent a science consensus. The broad aquaculture expertise contained within WGAQUA and other EGs working on aquaculture topics represents a valuable resource to ICES that can target the needs of a wide range of clients.

The ICES response to the special advisory request from OSPAR (OSPAR 4/2014) served as the most recent test-case of the effectiveness of the ICES advisory process to reach a science consensus on a major aquaculture issue in a transparent manner. The WGAQUA review of potential interactions between wild and captive fish science, and the conclusions reached are contained in the 2014 interim report (WGAQUA, 2014). The final advisory document to OSPAR (ADGFISH, 2014) was prepared based, in part, on this review. As this was the first formal advisory process for WGAQUA, the outcome and lessons learned became a major topic of discussion at the 2015 annual meeting.

WGAQUA was established in response, at least in part, to the 2012 ICES Aquaculture Discussion Paper (ICES 2012). A vision and strategy was outlined to meet the key challenges related to organizing aquaculture science in ICES in an effective manner and to handle the new needs for advice by member states. This included the organizing of WGAQUA as a "super-group" with "a broader role to administer the subgroups and to act as a reviewer or develop reviews based on the inputs by the subgroups" (ICES 2012). WGAQUA was also tasked with maintaining a functional working relationship with other EGs dealing with aquaculture related issues in order to best collaborate on addressing advisory requests. Towards this outcome, the science advice chair submitted a request to the ACOM secretariat offering assistance to coordinate multiple EG responses to the OSPAR request. However, this request was refused. Given the resulting lack of coordination, the ambiguity in the advice requested by OSPAR subsequently resulted in different interpretations by the participating EGs and by the ACOM Advice Drafting Group. This ambiguity eventually resulted in much of the work provided by WGAQUA being excluded from the final document sent to OSPAR (see below). Coordination among EGs would have facilitated a standard interpretation of the question at hand and provided a clear division of EG responsibilities.

Initial scoping of the advisory request revealed that it addressed a very broad range of sub-topics and included all species under culture across the entire ICES region. Initial work plans indicated that a deadline extension was needed to thoroughly complete the task, which included the need for an ecosystem approach. However, an early extension request to the ACOM secretariat was also denied. This led to the inability to fully address some fishery interactions with aquaculture and to explore potential mitigation measures within individual cultured species and for specific regions.

Given the lessons learned from this past advisory process, future requests will be closely scrutinized by WGAQUA prior to accepting the request for advice. This initial scoping exercise will consider the following:

1) Is the question well defined and is there capacity for WGAQUA to communicate with the client to clarify and assist in drafting the advisory request?
2) Is the geographic area too large (i.e. all ICES regional seas) to provide a clear response owing to site- and regional-specific factors?
3) Is the topic too broad (i.e. all cultured fish and/or shellfish) to provide a clear response?
4) Will responses from the various participating EG groups overlap?
5) Is the time-line for the advice adequate to provide a thorough response, including obtaining a group consensus?

In addition to the above concerns regarding the lack of coordination of EGs responding to this aquaculture advisory request, several major concerns were identified regarding the preparation of the final advice document that was submitted to OSPAR. The WGAQUA reviewed the report prepared by the Advice Drafting Group (ADGFISH, 2014) and concluded:

1) the advice was too narrowly focused to adequately address all aspects of the question provided by OSPAR, and more importantly,
2) the report did not represent an ICES aquaculture science consensus.

We believe that these shortcommings resulted from an advice drafting process that is not inclusive of the broad range of aquaculture expertise needed to participate directly in drafting the advice, and the inability for the peer-reviews and draft advice to be reviewed/revised by the main body of experts that populate the EGs. In brief, the one-way, four step advisory process between the provision of an EG advisory document and the presentation of the summary report to the client by ACOM does not ensure that an ICES aquaculture science consensus is presented to the client.

Although WGAUQA was critical of a large number of conclusions presented in the final report (ADGFISH 2015), the three major issues of contention were:

1) Exclusion from the final report of all relevant topics related to interactions between shellfish aquaculture and wild fish. This represented several chapters in the WGAQUA response. This decision by ADGFISH does not promote the multi-disciplinary, ecosystem approach advocated by WGAQUA. It also negatively affected the capacity of WGAQUA to maintain a delicate balance of members with interests in fish and shellfish topics.
2) Exclusion of several finfish topics that are highly relevant to adequately addressing the advice request. These were excluded simply because they were not specifically identified in the *examples* of potential interactions provided by OSPAR. This sends the message that the experts should not attempt to be thorough but just do the minimum amount of work.
3) Ignoring the major conclusion of the WGAQUA report and drafting statements that were both contrary to this conclusion and not peer-reviewed. Specifically, WGAQUA concluded that "aquaculture activities in the ICES and

> OSPAR regions are highly diverse and impacts on wild fish may be expected to be highly site-specific. Consequently, it was not possible for WGAQUA to reach generic conclusions on aquaculture interactions with wild fish, or to identify and prioritize major mariculture pressures that are applicable across the full ICES or OSPAR regions." Notwithstanding this carefully considered conclusion by a large and widely represented EG, ADGFISH stated that our response was particularly weak on addressing management solutions and suggesting a way forward to manage these pressures. This small group then drafted and presented their own solutions and conclusions to OSPAR without any peer-review.

Requests from WGAQUA to ACOM to try and improve the draft report prepared by ADGFISH were rejected as being contrary to the ICES advisory process. WGAQUA therefore concluded that this advisory process does not, and currently cannot, ensure that a science consensus on aquaculture issues is obtained: thus greatly reducing the credibility of ICES advice.

The above outcomes from the OSPAR aquaculture response highlight the need for an aquaculture advisory process that is more transparent, communicative, credible and effective, and which promotes feedback loops between the EGs, peer-reviewers and the Advice Drafting Group. Presently, this feedback is somewhat facilitated by participation of the EG chairs in the ADG. Given that EG chairs generally have research and management commitments and often must travel long distances, this is a delicate link that is easily broken. Greater flexibility is required in setting the date of the ADG meeting to ensure the mandatory participation of all applicable EG chairs. In addition, any content added to the draft report that contradicts the consensus of an EG should undergo independent peer-review and sign-off by the EG that provided the original advice. Deadlines should never contribute to the provision of inferior science advice to any client.

Improving the ICES Aquaculture Advisory Process

Figure 6.1 illustrates WGAQUA suggestions on areas where the ICES advisory process could be adapted to increase the coordination and participation of aquaculture experts in the preparation of science advice. In comparison with the traditional approach utilized by ICES, the recommended changes highlight the greater participation of WGAQUA in coordinating the aquaculture advisory process, in collaboration with ACOM, and the increased participation of all relevant EGs, the external peer reviewers and the Advice Drafting Group in the development of a science consensus report that will form the ICES response to the client.

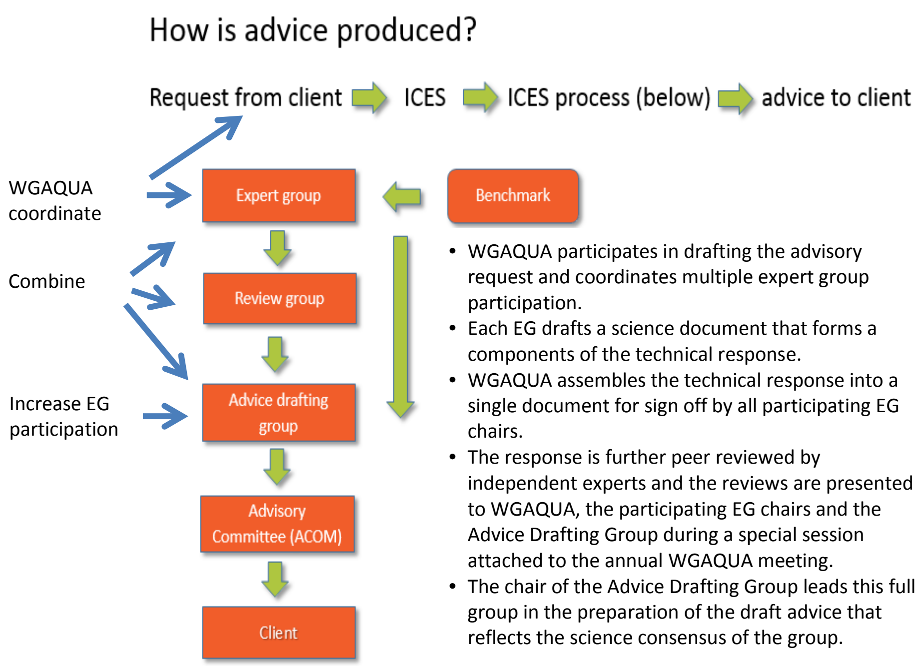

Figure 6.1. Conceptual framework for the provision of aquaculture science advice.

The following outlines the suggested responsibilities for each organization within ICES when tasked with the provision of science advice on an aquaculture issue:

ICES Secretariat:

1. Receipt of aquaculture request for advice from governments or international organizations (NASCO, OSPAR.., including ICES).
2. Formulate the "Term of Reference" in correspondence with the contracting authority, the WGAQUA Science Advice chair, and an ACOM representative. The "Terms of Reference" should contain:
   a. Objective of the advice request.
   b. Clear description of the questions raised.
   c. Clear description of the expected response from ICES.
   d. Estimation of the workload and EGs needed to obtain the answers.
   e. Establish a budget for the advice and the deadline.
3. Submit the request to WGAQUA.

WGAQUA:

4. Evaluate the "Terms of References" and ask for additional clarifications, via the Science Advice Chair, if needed on any of the sub-points.
5. The Science Advice Chair corresponds with other relevant EG chairs who collectively or individually decide to accept/deny the request for advice.
6. Appoint an advisory group (AG) consisting of highly qualified EG (WGAQUA and/or other relevant EGs) members and led by the Science Advice Chair of WGAQUA. Each EG participating in the AG will be tasked with the provision of

clearly defined components of a Draft Science Document that addresses the ToR question. Additional expertise from outside ICES may be invited by the chair to participate in the AG.

7. The Science Advice Chair will organize a special session, held during the WGAQUA annual meeting, to peer-review the Draft Science Document prepared by the AG and to assist in the preparation of the ICES advice. All participating EG chairs will be invited to participate. External peer-reviewers of the Draft Science Document will be invited to present their reviews to this group. This full group will comprise the Advice Drafting Group tasked with preparing the Draft Advice Document after reaching a science consensus.
8. Revise the Draft Science Document to reflect responses to the peer-review and submit the Final Science Document to SCICOM as part of the WGAQUA annual report.

ACOM:

9. An ACOM representative with a background in aquaculture research will chair the special session of the WGAQUA meeting that forms the Advice Drafting Group (Section 7).
10. Lead the preparation of a consensus summary document (Draft Advisory Report) that includes all major conclusions reached in the Final Science Document.
11. Include any dissenting science opinions outlined in the Science Document in the Draft Advisory Report.
12. Submit the Draft Advisory Report to the ACOM delegates for approval and presentation to the client.
13. The ACOM delegates may return the advice to WGAQUA with requests for additional information/revisions in the next review cycle.

The ICES Aquaculture Dialogue scheduled for Bergen, Norway on 1–2 June (2015) is an opportunity to discuss the advisory process as it relates specifically to addressing aquaculture issues. The WGAQUA believes that this discussion is critical to assure the quality, transparency, and legitimacy in aquaculture advice so that users and stakeholders have confidence in the advice provided.

Annex 7: WGAQUA and the International Organization for Standardization

ICES currently holds liaison A status with ISO Technical Committee 234 (Fisheries and Aquaculture). This committee develops standards related to terminology, technical specifications for equipment and for their operation, characterization of aquaculture sites and maintenance of appropriate physical, chemical and biological conditions, environmental monitoring, data reporting, traceability and waste disposal. Organizations that make an effective contribution to the work of the technical committee or subcommittee have access to all relevant documentation and are invited to meetings. They may nominate experts to participate in a working group.

Liaison A status allows ICES to make an effective contribution to the work of ISO technical committees or subcommittees with access to all relevant documentation and invitations to participate in meetings. ICES may also nominate experts to participate in a working group. WGAQUA responsibilities under this liaison status with ISO lie with the Science Advice Chair, who monitors the ISO balletting process to inform the ICES secretariat of any aquaculture activities that require attention. WGAQUA is currently not participating on any ISO working groups as these were close to finalizing their work when ICES joined. However, WGAQUA has agreed to participate in a newly proposed ISO theme (ISO/NP 18860) entitled ``Terminology and formulas describing conversion of marine raw materials (fish oil and fishmeal) into aquaculture output``. David Bengtson (USA) volunteered to have his name put forward by the ICES secretariat to participate in this ISO exercise. The deadline for submitting the ICES response via ISO balloting is 16 April, 2015.

In response to an onging request from ISO for ICES to provide input on the possible development of new standards, a group discussion resulted in the following list:

a) Develop standards for environmental data collection related to the assessment of a new site for aquaculture development (e.g. determine what measurements are required and how/where are they made).

b) Develop standard criteria for establishing new aquaculture sites (i.e. decision support system).

c) Develop a quantitative definition of an Integrated Multi-Trophic Aquaculture (IMTA) arm based on required cultured species interactions and efficiency of waste recycling/extraction. This is needed for regulatory and certification purposes.

d) Develop standard methodologies for accurately measuring the number of fish contained in fish pens.

Annex 8: Status of Aquaculture Science and Advice in ICES

ToR a: Synthesise reports and recommendations by WGAGFM, WGPDMO, WGHABD, and WGECO on the environmental dependence and effects of aquaculture.

ToR b: Synthesise previous science advice provided by ICES SGs and WGs related to sustainable aquaculture.

Overview of ICES Expert Group Activities Related to Aquaculture

The work of WGAQUA on ToR a and b both included reviewing the contents of past ICES expert group reports to extract and synthesize information that may be relevant to the WGAQUA workplan. This exercise was also conducted to avoid overlap between expert group activities, to assist in linking topics of common interest, to integrate work products, and to communicate outputs across ICES expert groups. Annual reports generated between 2003 and 2014 by the SGSA/WGSEDA, WGAGFM, WGPDMO, WGICZM/WGMPCZM, WGITMO, WGEIM (last year was 2012) and WGMASC (last year was 2012) were divided among WGAQUA members with the task of identifying and summarizing topics addressed related to:

1) the environmental dependence and effects of aquaculture (ToRa), and

2) advise and recommendations related to sustainable aquaculture (ToRb).

In order to demonstrate and maintain the close linkages between the science and advisory activities of these ICES expert groups, ToR a and b overviews were addressed and reported concurrently.

The WGEIM and WGMASC ToRs were dedicated to aquaculture and these groups were combined to form WGAQUA. Consequently, their tasks and outputs are well known within WGAQUA and only their publications are listed along with a summary of topics in tabularised form. For these groups, our focus was on reviewing their advisory activities. Additional working group activities (e.g. WGHABD and WGECO) are also relevant but had been reviewed previously as part of activities conducted by the WGEIM, WGMASC and WGICZM.

1.1 ICES Working Group on Introduction and Transfers of Marine Organisms (WGITMO)

Table 1.1. Aquaculture related topics from the ICES Working Group on Introduction and Transfers of Marine Organisms (WGITMO)

Topic	2007	2008	2009	2010	2011	2012	2013	2014
1	Identify and report on changes in the distribution, population abundance and condition of introduced marine species							
2	Develop Alien Species Alert report, including evaluation of impacts, and to increase public awareness on the Pacific oyster *Crassostrea gigas.*							
3			Development of criteria for the creation of high-low risk species lists					
4						Coordinate reporting of nonindigenous pathogens affecting mariculture with the relevant ICES expert group(s) and establish a mechanisms for annually exchanging relevant information.		
5						Investigate and report on new developments in non-native species issues associated with biofouling (e.g. artificial structures in the marine environment and recreational boating) (joint Term of Reference with WGBOSV)		

1.1.1 Summary of WGITMO outputs on aquaculture topics

2007:

- *Crassostrea gigas* was introduced as aquaculture but has since become established and is spreading throughout Europe. Species range expansions are not well documented as responses to temperature, salinity, and/or other climate change impacts. There is some evidence that changes in the rates of reproduction are related to warmer temperatures. Proposed to review the current status of knowledge concerning the *Crassostrea gigas* invasiveness. WGITMO suggests preparing intersessionally a Species Alert Report on the Pacific oyster *Crassostrea gigas* with the aim to finalize the report in 2008.

2008:

- Discussed the IMPASSE Risk Assessment Scheme which provides protocols for assessing the risks of using alien species in aquaculture'. This is the scheme to be used in Europe for compliance with the new EU Regulation of the use of alien species in aquaculture. The current UK scheme was used as an example to assess the Pacific oyster Crassostrea gigas, which was introduced to Europe in 16th century (Portugal), and then again in 1960s and 1970s. The species is now farmed in large part in France, and it is spreading along European coasts. The assessments were carried with currently uninfested areas of the Normandy and UK coasts as the risk assessment areas. For the initial, hazard identification, phase of these assessments, the marine invertebrate invasiveness scoring kit (MI-ISK) was used to assess invasive-ness potential (www.cefas.co.uk/4200.aspx). The outcomes of these assessments were largely similar, with both resulting in 'high risk' MI-ISK scores, with medium-to-high impact ratings and medium uncertainty levels using the UK scheme.

2009:

- WGITMO agreed that the current approach for evaluating national reports on the spread of invasive species was not effective.

2010:

- One aquaculture release was reported by the U.S. Adults of the shrimp *Penaeus monodon* were observed off the coast of North Carolina, but no reproducing populations were found. This is the northern-most sighting for this species which is from Guyana. *Crassostrea gigas* is also an aquaculture escapee and is reported as range expansion in Ireland.
- Provided information on regulations concerning use of non-native species in aquaculture. The regulations include a rank of Low risk for species that have been in aquaculture for a long time and have no reported impacts. High risk considers species problematic unless proven otherwise. Screening is required to determine if high risk. The issue of what to do with the medium risk remains the conundrum. The European Union needs to consider other EU states' concerns about species they want to use in aquaculture. For example, EU document, Paragraph 6 – provides guidance on risk assessment and notes the community should develop own framework but in the short excerpt there is no mention of ICES Code of Practices and risk assessment guidelines. In the EU regulations, veto power of neighbouring states is not addressed.

2011:

- Problem species in the Netherlands are the oyster drills *Urosalpinx cinerea* and *Ocinebrellus inornatus.* The expansion of *Ensis directus* and *Crassostrea gigas* continued. Both are dominating the benthic community in the Dutch coastal waters. The Pacific oyster (*Crassostrea gigas*) has suffered substantial set-back on studied localities (harsh winter) in SE Norway.
- The Council Regulation (EC) No 708/2007 concerning use of alien and locally absent species in aquaculture was considered. It was suggested that the generic ICES Code of Practice definition of risk should be left as it is currently defined. It was proposed that the ICES CoP be revised to make it clear that the Risk Assessment is only the first step, and explain the roles of different groups involved in the decision making.

2012:

- Important persistent aquatic invasive species in Atlantic Canada are green crab (*Carcinus maenas*) and tunicate species. These are also considered as new and future aquatic invasive species within this region as these organisms are spreading from one Atlantic province to the next.

2013:

- Biofouling of artificial structures appears to be a truly global issue. Several types of artificial hard-substrate installations have been created for decades both in ICES and non-ICES waters, such as oil/gas platforms, pipelines, port facilities and wind tur-bines. Movable structures (e.g. oil platforms) can certainly act as vectors, while non-mobile structures (e.g. wind turbines) may facilitate invasions through 'stepping stone' transfers or when structures are decommissioned. Aquaculture structures were not mentioned specifically.
- For initiating periodic reporting of nonindigenous parasites, pathogens and other disease agents affecting mariculture and advance related research, request WGH-ABD, WGAQUA and WGPDMO to provide WGITMO any information on availabil-ity of potentially relevant data/information sources (incl. location of datasets), and on current monitoring/reporting practices in ICES area and elsewhere.

2014:

- Investigate and report on new developments in non-native species issues associated with biofouling (e.g. artificial structures in the marine environ-ment and recreational boating) (joint Term of Reference with WGBOSV). Aquaculture structures were not mentioned specifically.

1.1.2 Summary of WGITMO advice/recommendations on aquaculture topics:

2007:

- The aquaculture industry should find the information in the National Reports on parasites, pathogens and other disease organisms useful, and but it is uncertain that they are receiving the information.

2008:

- Risk Assessment approaches continue to evolve and will be a topic for continued updates for WGITMO. WGITMO recommends that wild and aquaculture *C. gigas* populations be discussed in the report.

2009:

- *Evaluating national reports on the spread of invasive species:*
  - The group should focus on creating a set of data using sources other than the national reports that can then be compiled into a report looking at invasion status and trends, as was done for the earlier algae and higher plant sections. This type of report could also be used to start looking at effects that are expected as a result of climate change and to compile all the information the group has on vectors.
  - Another suggestion was to build on the current excel spreadsheets that are submitted with the national reports to build a solid AIS dataset within the ICES statistical database. It was not clear if this option was technically feasible, nor was it clear how to include information from countries that are not reporting annually.
  - It was decided that only species which have at least part of their lifecycle in the marine or brackish environments should be included in reports.
- The report on the status of *C. gigas* needs to be finalized
- *Development of criteria for the creation of high-low risk species lists:* It was recommended that because this is a complex issue that is not going to be resolvedin 2009, the group should work intersessionally to describe the work that is already underway in many countries and to identify major issues of concern, such as genetics and climate change. This will be compiled into a white paper that will be sent to ICES for their review and consideration.

2010:

- From the ICES PICES Joint Meeting it was recommended to develop and share a database on marine invaders and taxonomic experts.

2011:

- Concerning the quality of the invasive species database, it was stated that an editorial board of the database is needed. It should consist of specialists having knowledge on regional seas and taxonomic group experts. The editorial board should oversee that species names in the database are valid, that species are identified correctly and that all species related attributes such as biological traits, environmental data, possible introduction vector, impacts and other information are all accurately indicated in the database. The rough estimate is that 15-20 persons per regional sea would be required.

2012:

- The ICES Code of Practice (CoP) on the Introductions and Transfers of Marine Organisms should be made available via ICES webpage.

2013:

- A Clams and Cockle Fishery from Ria de Arousa (NW Spain) has been recommended for a Marine Stewardship Council (MSC) certificate. Four species are included in this fishery, among which there is the NIS Manila clam, Ruditapes philippinarum. By recommending the certification of a well-documented environmentally harmful invasive species, the MSC will end up harm-ing the environment as well as risking its credibility.

2014:

- Invasions may over time reach a balanced coexistence with the native species, possibly resulting in a localized net diversity gain. However, the impacts of non-indigenous species should not be neglected, especially during their mass developments.

1.1.3 References

ICES. 2007. Report of the Working Group on Introductions and Transfers of Marine Organisms (WGITMO), 21–23 March 2007, Dubrovnik, Croatia. ICES CM 2007/ACME:05.160 pp.

ICES. 2008. Report of the Working Group on Introduction and Transfers of Marine Organisms (WGITMO), 12–14 March 2008, Copenhagen, Denmark. ICES CM 2008/ACOM:52. 130 pp.

ICES. 2009. Report of the Working Group on Introduction and Transfers of Marine Organisms (WGITMO), 11 - 13 March 2009, Washington D.C., USA. 220pp.

ICES. 2010. Report of the ICES Working Group on Introductions and Transfers of Ma-rine Organisms (WGITMO), 10 - 12 March 2010, Hamburg, Germany. ICES CM 2010/ACOM:29. 130 pp.

ICES. 2011. Report of the Working Group on Introduction and Transfers of Marine Organisms (WGITMO), 16 - 18 March 2011, Nantes, France. ICES CM 2011/ACOM:29. 180 pp.

ICES. 2012. Report of the ICES Working Group on Introduction and Transfers of Marine Organisms (WGITMO), 14 - 16 March 2012, Lisbon, Portugal. ICES CM 2012/ACOM:31. 301 pp.

ICES. 2013. Report of the ICES Working Group on Introduction and Transfers of Marine Organisms (WGITMO), 20 - 22 March 2013 Montreal, Canada. ICES CM 2013/ACOM:30. 147 pp.

ICES. 2014. Report of the ICES Working Group on Introduction and Transfers of Marine Organisms (WGITMO), 19-21 March 2014 Palanga, Lithuania. ICES CM 2014/ACOM:32. 259 pp.

1.2 ICES Working Groups on Integrated Coastal Zone Management (WGICZM) and WG on Marine Planning and Coastal Zone Management (WGMPCZM)

Table 1.2. Aquaculture related topics from the ICES Working Group on Integrated Coastal Zone Management (WGICZM), which became the WG on Marine Planning and Coastal Zone Management (WGMPCZM) in 2011.

Topic	2006	2007	2008	2009	2010	2011	2012	2013	2014
1	Development of a framework for integrated evaluation of human impacts in the coastal zone					Spatial planning tools to assist IM practitioners. Quality assurance in management plans			
2		Update and report on ICZM activities in different ICES Member Countries							
3			Update and report on activities of relevant ICES groups to identify information pertaining to coastal zone and evaluate this information relative to ICZM needs and review progress from the EU and IOC						
4			Standardised methods for indicator selection						
5				Evaluate the usefulness of assessing ecosystem goods and services in ICZM		Socio-economic understanding of ecosystem goods and services			
6						Application of IM to address interactions between commercially exploited species and			

						natural systems including aquaculture		
7								Thresholds of acceptable environmental (social and ecological) change due to regional and transboundary activities in the context of MSP processes

1.2.1 Summary of WGICZM and WGMPCZM outputs on aquaculture topics

2006:

- A specific role for ICES within a framework for integrated evaluation of human impacts in the coastal zone could be to deliver the baseline information and expertise to develop a model to assess the vulnerability of marine and coastal ecosystems to changes which relate to human activities. The next step would be is to integrate the vulnerability assessment with risks associated to human activities. Human demands for coastal and marine space and resource use including Coastal Zone Conflict could be organised in the following manner:
    - Identification of human activities such as urbanisation, tourism, aquaculture, energy production or other uses;
    - their interactions with coastal and marine ecosystem processes;
    - the risk associated with these activities to create a severe impact on ecosystem functions (e.g. risks from oil spills, pollution,…);
    - problems that may arise such as xenobiotic organisms introduced directly or indirectly by human activities.

2007:

- Provided an Annex (#5) summarizing key issues, impacts and information gaps related to mariculture and coastal ecosystems as identified by other working groups.

- Provided an Annex (#6) identifying ICES member countries where aquaculture is a key activity, the relevant ICZM legislation and the presence of ICZM projects and management initiatives.

2008:

- identified the need for integrated decision making frameworks as opposed to standardised lists of indicators and the necessity of specified management objectives at an appropriate scale. Noted that it is not feasible to apply a single list of indicators to all monitoring programmes. Nevertheless, it was proposed that coherent and coordinated methods of selecting and implementing indicators, selecting comparable measures wherever applicable were essential.

2009:

- Evaluating ecosystem goods and services, particularly in economic terms, is a valuable way of communicating the importance of environmental sustainability to the public. It is important to recognize that there are many non-market values that should be assigned to ecosystem goods and services (i.e. social, cultural, existence, intrinsic, spiritual, option). Assigning a tangible value to ecosystem goods and services, which can be approached from many disciplinary perspectives, facilitates discussion and evaluation of management actions that are based on quantifiable costs and benefits.

2010:

- Most ICES countries still have fragmented responsibilities for legislation and policies among authorities, and a lack of a legal framework to support ICZM nationally and internationally. This raises concern over the lack of compatibility among legislations at the national and ecoregion (ICES) levels and the inefficient collection, communication, dissemination, and compatibility of available data sets. It has also become clear that many of the key issues facing decision-makers in the coastal zone are localised and therefore require a local solution.
- Outlines the COEXIST, AQUA REG and ECASA projects that deal with the sustainable development of aquaculture and related tools.
- Outlines key issues for ICZM in several countries (Germany, Norway and the UK) related to aquaculture activities.

2011:

- Examples of aquaculture marine spatial planning (MPS) noted during discussions of large-scale MSP development and guidelines for best-practice.

2012:

- The challenge of MSP is to allocate sea space in line with the ecosystem approach and in a way that achieves an acceptable distribution of risks and opportunities to the communities and economies affected. This leads to three requirements: a) to get to know the resource (ecology, different sea values, goods and services), b) to establish risks that new uses or cumulative impacts might bring to the resource and to goods and services, and based on these, c) to set priorities for MSP and/or management.

- For MSP, a key concern is to develop methods for identifying cultural values and for mapping those areas that are of particular importance for cultural reasons.
- Identified three main topics important for quality assurance: 1) Unbiased scientific peer review process of management advice, 2) QA in terms of governance; setting objectives, regulatory process etc. 3) QA in relation to environmental effects monitoring, regulatory decision making and verification and auditing of environmental management plans.

2013:

- The added value and therefore the role of science in MSP/ICZM is in assisting to help separate facts and perceptions, creating insights in how the ecosystem works or might be influenced, identify research topics in cooperation with the leaders of MSP and ICZM processes and the stakeholders participating in them.

2014:

- Cormier, R., Kannen, A., Elliott, M., Hall, P., Davies, I.M. 2013. Marine and coastal ecosystem-based risk management handbook. ICES Cooperative Research Report No. 317. 60 pp.,
- Cormier, R., Davies, I., and Kannen, A. (Eds.) 2013. Integrated coastal-zone risk management. ICES Cooperative Research Report 320. 145 pp.,
- Evaluation of the potential for co-location of activities in marine plan areas in UK and The Netherlands.

1.2.2 Summary of WGICZM and WGMPCZM advice/recommendations on aquaculture topics:

2006:

- WGICZM recommends that ICES works to develop a model to assess the vulnerability of marine and coastal ecosystems to changes which relate to human activities. Having progressed this far, the next step is to integrate the vulnerability assessment with risks associated to human activities.
- WGICZM further recommends that ICES continues to:
    - develop ecological quality objectives and indicators on environmental quality in coastal- and transitional waters;
    - establishes reference conditions/values, assesses interplay between natural variability and cycles and pressure due to human activities;
    - further examines the effects of changes in climate for the coastal zone;
    - Revisits the categorization of coastal water, transitional waters and heavily modified water bodies done by different EU-countries;
    - Examines how to tackle cross-boundary pressures, for example long-distance transport of nutrients and pollutants, shipping;

  - Defines scientific based limits for high, good and moderate ecological status;
  - Advices on monitoring and surveillance programmes and methods for coastal monitoring;Promotes comparative studies, inter-calibration exercises and a sound scientific basis for the implementation of the WFD; and
  - Considers potential and realism in enterprises and measures to improve ecological status in coastal- and transitional water.

2007:

- ICES continues to develop ecological quality objectives and environmental quality indicators in coastal and transitional waters.

2008:

- The WGICZM recommends continuing to update and report on activities of relevant ICES working and studying groups to identify information pertaining to the coastal zone and evaluate this information relative to ICZM needs and to monitor progress within the EU and IOC.
- It was recommended that the WGICZM work towards:
  - Bringing together the risk characterisation and the indicator characterisation approaches within an integrated decision-making framework.
  - Developing a general framework for the indicator selection process for ICES countries. Within that framework should be the clear definition of objectives and the integration of the indicator system into the overall management process.
  - Exploring the possibility of putting together a proposal developing the integrated decision making framework for ICZM.

2009:

- ICES promote the adoption of a harmonized, structured decision-making framework for ICES Member States. By continuing to monitor existing and emerging decision-making tools and frameworks, WGICZM will be able to contribute to this recommendation and provide advice to ICES
- The process of assessing ecosystem goods and services can provide valuable contributions to the decision-making process but should be used in conjunction with other tools. It is recommended ICES take the position that the assessment of ecosystem goods and services should be based on strong sustainability principles.

2012:

- An ICES Cooperative Research Report (CRR) on Risk Analysis (RA) Framework was prepared with procedures for risk management in mind and adopting ISO language of risk management. It highlights key tools and a sequence of steps involved in RA.

2013:

- There is a need for education and training of (future) practitioners both as specialists who can be leading the MSP/ICZM processes and for others involved (such as ICES scientists) to get a clear understanding of their role, potential added value and in the terminology used in marine planning.

2014:

- In Norway the aquaculture management reform, conflicts of interest, the aquaculture industry's perceptions of their role in local communities, inter-municipal cooperation, knowledge production and use in CZ management, the actual use and potential for economic value creation as input and argument in CZ management, the distribution of benefits from aquaculture and the incentives this creates for area management, and politics and policies to influence the distribution was studied in a national project. One conclusion was: if the aquaculture industry wants access to more areas in the fture, a system that provides reasonable benefits to all municipalities hosting fish farms must be established.

1.2.3 References

ICES. 2006. Report of the Working Group on Integrated Coastal Zone Management (WGICZM), 19–21 April 2006, ICES Headquarters, Copenhagen. ICES CM 2006/MHC:08.107 pp.

ICES. 2007. Report of the Working Group on Integrated Coastal Zone Management (WGICZM), 17-20 April 2007, . CM 2007/MHC:09. 69 pp.

ICES. 2008. Report of the Working Group on Integrated Coastal Zone Management (WGICZM), 11–14 March 2008, Mallorca, Spain. ICES CM 2008/MHC:05. 111 pp.

ICES. 2009. Report of the Working Group on Integrated Coastal Zone Management (WGICZM), 24–27 March 2009, GKSS Research Centre, Geesthacht, Germany. ICES CM 2009/MHC:06. 89pp.

ICES. 2010. Report of the Working Group on Integrated Coastal Zone Management (WGICZM), 9-12 March 2010, Mallorca, Spain. ICES CM 2010 / SSGHIE:05. 69 pp.

ICES. 2012. Report of the Working Group for Marine Planning and Coastal Zone Management (WGMPCZM), 20–23 March 2012, ICES Headquarters, Copenhagen, Denmark. ICES CM 2012/SSGEF:07. 91 pp.

ICES. 2013. Report of the Working Group for Marine Planning and Coastal Zone Management (WGMPCZM), 8-10 April 2013, ICES Headquarters, Copenhagen, Denmark. ICES CM 2013/SSGEF:07. 206 pp.

ICES. 2014. Report of the Working Group for Marine Planning and Coastal Zone Management (WGMPCZM), 7–11 April 2014 Barcelona, Spain. ICES CM 2014/SSGHIE:06. 41 pp.

1.3 ICES Study Group on Socio-Economic Dimensions of Aquaculture (SGSA)

Table 1.3. Aquaculture related topics from the ICES Study Group on Socio-Economic Dimensions of Aquaculture (SGSA)

Topic	2011	2012	2013	2014
1	Methods to assess the direct and indirect socio-economic consequences of the use of marine space by aquaculture			
2	Identifying and strengthening local stakeholder inclusion and local ownership in the aquaculture production chain	Examine how inclusion and local ownership influence aquaculture		
3	Address how social values and administrative organizations in different countries/regions affect trends in the intensity, methodology, acceptance, structure and type of aquaculture			
4	Identify new emerging issues of socio-economic aspects of aquaculture			
5		Identify how social, economic, governance and environmental framing conditions influence aquaculture development		
6				Individual and cross-cutting, integrative methods to support the evaluation of the direct and indirect socio-economic consequences of aquaculture operations and how they relate to the assessment framework

7				Examine the role of aquaculture in economic development and in regional and global food security and protein supply

1.3.1 Summary of SGSA outputs on aquaculture topics.

2011:

- A clear definition of socio-economic and ecological objectives for all aquaculture operations is necessary which acknowledge the social, economic and ecological dimensions.
- A stronger consideration of the distribution of benefits (related to inputs and outputs) throughout the social-ecological system is recommended (who is benefiting and to what extent).
- Significant progress has been made towards evaluating the socio-economic and, perhaps even more, the ecological impacts of aquaculture, although less progress has been made towards utilizing this information to influence management decisions. The SGSA has developed a preliminary framework for an integrated assessment of the socio-economic dimensions of aquaculture.
- Many aquaculture assessments focus primarily on the impacts of the activity without enough consideration of the framing conditions that are driving those impacts or that influence how the impacts are managed. Understanding the local context (social, political, environmental, economic) is critical to the effective evaluation and management of aquaculture scenarios.

2012:

- Identified a preliminary list of methods, which could support an integrative assessment within a social-ecological framework.
- Need to establish knowledge bases for decision-making via stakeholder inclusion, for example through an environmental or social impact assessment. Include stakeholders and their supporting values in the decision-making process.
- Need to carry out a systematic identification of framing conditions (Understanding the local context) of aquaculture as a key step towards informing management measures that will enable aquaculture to realize its full potential. Tools for the assessment of these framing conditions need to be identified.
- The socio-economic implications of certification schemes was flagged as a key emerging issue.

2013: no report

2014:

- Pre-emptive identification of likely social impacts of aquaculture operations (using appropriate system boundaries) before any attempts are made to introduce aquaculture.
-

1.3.2 Summary of SGSA advice/recommendations on aquaculture topics:

2011:

- There should be an explicit acknowledgement of the complex, interrelated social, economic and ecological dimensions of aquaculture operations. These pertain to direct and indirect impacts but also to the socio-economic and environmental framing conditions under which aquaculture projects are developed and implemented.
- Any detailed analysis of the inputs and outputs of aquaculture, should include an assessment of the spatial scales at which the variables act and the distribution of benefits (related to inputs and outputs).
- It was recommended to develop/review a methodological framework and tools for the assessment of socio-economic framing conditions. Potentially amenable tools include Rapid Rural Appraisal (RRA), Sustainable Livelihoods Approach (SLA) and New Institutional Economics (NIE). The SGSA recommends that future research related to aquaculture should place more emphasis on these dimensions 2012:

2012:

- Understanding the local context (social, political, environmental, economic) is critical to the effective evaluation and management of aquaculture scenarios. This is especially pertinent with respect to socio-economic framing conditions which are often overlooked in scientific studies. The role of faming conditions must be stronger emphasis in future research
- Include stakeholders and their supporting values in the decision-making process.

2013: no report

2014:

- Equal consideration of ecological, social and economic issues in aquaculture policy-making.
- Integration of people- and context-specific social framing conditions into planning and policy review
- Addressing the social disconnect between global consumption and production via stakeholder participation and continuous transdisciplinary dialogues
- Encouragement of creative combinations of theories and methods widely applicable to assess and interpret the social dimensions of aquaculture in multiple contexts

1.3.3 References

ICES. 2011. Report of the Study Group on Socio-Economic Dimensions of Aquaculture (SGSA), 12–14 April 2011, Bremen, Germany. ICES CM 2011/SSGHIE:11. 31 pp.

ICES. 2012. Report of the Study Group on Socio-Economic Dimensions of Aquaculture (SGSA), 24-26 April 2012, Stockholm, Sweden. ICES CM 2012/SSGHIE:10. 41 pp.

ICES. 2014. Report of the Study Group on Socio-Economic Dimensions of Aquaculture (SGSA), 22-24 April 2014, Biddeford, Maine, USA. ICES CM 2014/SSGHIE:11. 28 pp.

1.4 ICES Working Group on Marine Shellfish Culture (WGMASC)

Table 1.4. Aquaculture topics from the Working Group on Marine Shellfish Culture (WGMASC).

Topic	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
1	Hatchery impact on shellfish production, application of genetic tools and genetic consequences on natural populations									
2	Stress indicators to explain mortalities									
3	Ecological factors affecting shellfish production and performance indicators									
4	Sustainability of shellfish culture									
5				Framework for the integrated evaluation of shellfish aquaculture impacts in the coastal zone						
6				Hatchery enhancement of wild fisheries						
7						Effect of bivalve aquaculture transfers between sites to wild and cultured bivalve stocks				

						Evidence for and effect of climate change on shellfish aquaculture distribution and production		
								Site selection criteria in molluscan aquaculture with particular reference to accessing and developing offshore facilities

1.4.1 Summary of WGMASC publications on aquaculture topics

- Cranford PJ, Kamermans P, Krause G, Mazurié J, Buck B, Dolmer P, Fraser D, Gubbins M, Van Nieuwenhove K, O'Beirn FX, Sanchez-Mata A, Thorarinsdóttir GG, Strand Ø. 2012. An ecosystem-based approach and management framework for the integrated evaluation of bivalve aquaculture impacts. Aquaculture Environmental Interactions 2: 193-213.
- Muehlbauer F., D. Fraser, M. Brenner, K. Van Nieuwenhove, M. Gubbins B. H. Buck, O. Strand, J. Mazurié, G. Thorarinsdottir, P. Dolmer, F. O`Beirn, A. Sanchez-Mata, P. Kamermans. 2014. Bivalve aquaculture transfers in Atlantic Europe. Part A: transfer activities and legal background. Ocean and Coastal Management 89: 127–138
- Brenner M., D. Fraser, K. Van Nieuwenhove, F. O`Beirn, B. H. Buck, J. Mazurié, G. Thorarinsdottir, P. Dolmer, A. Sanchez-Mata, O. Strand, G. Flimlin, P. Kamermans. 2014. Bivalve aquaculture transfers in Atlantic Europe. Part B: environmental impacts of transfer activities. Ocean and Coastal Management 89: 139–146

1.4.2 Summary of WG advice/recommendations on aquaculture topics by topic:

1) Hatchery impact on shellfish production, application of genetic tools and genetic consequences on natural populations
    - Develop hatchery registration and a national survey on shellfish hatchery production
    - WGITMO should monitor the implementation of the Code of Practice on the Introductions and Transfers of Marine Organisms for hatchery produced shellfish
2) Stress indicators in shellfish to explain mortality events
    a. a preliminary diagnostic guideline be developed based upon the framework described in this report. This guideline should be created by individual experts in the field of environmental stress and should provide for a comprehensive protocol to aid in the identification of causes of mortality in cultured shellfish and recommend appropriate mitigation measures

b. An operational flowchart and set of working tables were developed to assess the types of mortality that a shellfish grower might encounter in the field and what may have caused these losses. This tool should be used by farmers and resource managers.
c. A monitoring system was also recommended to allow for early detection of problems and to provide a point of reference for future changes in shellfish production.
d. The diagnostic tool described in the ToR should be published and distributed to the farmers (e.g. through producer organisations) and the local managers in the languages of ICES countries. It is recommended, as a first step, that an ICES Cooperative Research Report be prepared on this topic. This report would be available to farmers, resource management and scientists and would serve as the foundation for additional discussion among experts and input from stakeholders that could lead to preparation of regional leaflets by responsible authorities.

3) Review of ecological factors affecting shellfish production, develop performance indicators
    a. A comparative study of different management systems should be carried out with a view to identifying and testing the response of indices under different production conditions and management regimes. The goal will be to identify the key indices
    b. Stakeholders should be consulted on the development of carrying capacity models so as to provide valuable input into potential constraints and assessing the value of selected performance indicators. The stakeholders should include industry members/representatives, conservation interests, regulatory representatives, and academia

4) Sustainability of shellfish culture
    a. Sustainability was defined by the working group as: "the husbandry and future development of cultured shellfish stocks without compromising the structure and function of the ecosystem". The WGMASC cannot state what impacts are acceptable. There are valid socioeconomic aspects to the sustainability question that cannot be addressed by scientists alone. Major roles of science are to advise on the potential consequences associated with aquaculture interactions with the environment, and to make recommendations towards the development of approaches for managing cultured shellfish stocks in a sustainable manner. Given the direct relation known to exist between the financial sustainability of the shellfish aquaculture industry and the ecological sustainability of coastal systems, environmental considerations need to be incorporated within management and development plans for shellfish aquaculture.

5) Framework for the integrated evaluation of the impacts of shellfish aquaculture activities in the coastal zone
    a. EAA be based on a tiered environmental monitoring approach that is structured on the principle that increased environmental risk requires an increase in monitoring effort.
    b. Local benthic geochemical and community parameters, while useful for site-specific environmental monitoring, are of limited value as indicators of changes at the ecosystem level. Some combination of modelling and measurement of selected far-field indicators related to benthic and pelagic communities, suspended particle depletion, shellfish performance is needed over relatively large (inlet-scale) areas to adequately assess the ecosystem level impacts of shellfish culture.
    c. Regulatory decisions be based on partitioning the range of variation of an indicator into more than two classes/categories (acceptable vs. unacceptable). A few more threshold classes permits implementation of mitigation measures prior to reaching an unacceptable ecological state.
    d. The introduction of the Marine Strategy and Water Framework Directives (also Canadian Oceans Act) mandates a DPSIR-type EAA approach that links ecological and socio-economic systems. It is therefore essential that the development of a management framework should be inclusive with diverse stakeholder participation, transparency and communication.

6) Hatchery enhancement of wild fisheries
    a. the integration of aquaculture and fisheries management techniques in order to enhance scallop production. Industry, policy makers and scientists act to assess the benefits of such methodology and facilitate plans for their use.
    b. Further genetic studies on scallop populations be undertaken to determine whether geographic-based genetic population structuring exists, which could influence future wild stock management regulations.

7) Bivalve aquaculture transfers between sites to wild and cultured bivalve stocks
    a. Moving shellfish within and between countries and ecosystems, poses a high risk of ecological impact, to genetic integrity and to the introduction and spread of invasive species and pathogenic agents. There should be a presumption against routine introductions and transfers of molluscan shellfish; these should only occur through necessity, e.g. in the promotion of free trade and only be made following a full risk assessment to demonstrate negligible risk. As global communication continues to develop it becomes increasingly important to develop a more dynamic and transparent global approach.

b. All possible alternatives at a local scale should be investigated before consideration of introductions as a last resort, e.g. employing hatchery or spat collection methods rather than importation.
c. Proper risk assessment should be undertaken, irrespective of cost, to ensure safety to ecosystems, as the long-term environmental and financial costs from introductions is unquantifiable in the long-term. Risk assessments should include possible effects of diseases (parasites, viruses and bacteria), genetical contamination and hitch hiking species.
d. Consultation on applications should be vigorous, be universally applied and be objective; and there should be a presumption against them, unless good scientific evidence proves otherwise.
e. Monitoring of translocation of spat inter and between countries should be implemented to minimize transfer related risks and minimize the impact of e.g. Germany who routinely imports mussels from Ireland and Denmark, with resultant concerns regarding speciation or the introduction of pests or diseases.
f. There is a need to regularly review and update regulations to account for and minimize the potential impact of emerging environmental or disease issues.
g. Consideration should also be given to the risk to native stocks from interbreeding. The resultant progeny invading ecosystems possibly being infertile, creating an imbalance within an ecosystem. If not infertile they may replace indigenous stocks
h. Conform to industry codes of practice and legislation; e.g. ensure that ille-gal transfers are not made and that certification procedures are kept
i. Develop and maintain a biosecurity measures plan
j. improve record keeping and make records available to official health experts;
k. employ best management practices of husbandry and hygiene to maximise health, growth and site production, with minimum impact on neighbouring sites.
l. Harmonise legislation: to ensure that existing and developing legislation is joined up in relation to its interpretation, understanding and implementa-tion by all stakeholders;
m. Improve dialogue with industry improve communication amongst farmers, scientists and policy makers, e.g. by forum meetings;
n. Apply enforcement more effectively; develop policy;
o. Best educate and implement biosecurity measures with industry, and scientists;
p. Develop and maintain a trusting open dialogue with industry;
q. Coordinate and develop legislation to maintain sustainability.
r. Financial consideration should be secondary to ecological impact, if a company wishes to profit from an introduction they should be prepared

to undertake proper scientific assessment of risk as long term impacts can be serious and wide ranging.

8) Evidence for and effect of climate change on shellfish aquaculture distribution and production
   a. There is a high probability that climate change and ocean acidification has already had and will continue to have consequences for the biogeographical distribution and productivity of cultured shellfish species that will alter their ecological roles and economic potential. Key interlinked global warming variables that can impact shellfish aquaculture include advection, vertical mixing, convection, turbulence, light, rainfall, freshwater run-off, evaporation, oxygen concentration, pH, salinity, and nutrient supply. Although the available studies reveal that some important culture species will be at increasing risk in the coming decades, research on the direct and indirect effects of climate change and ocean acidification on many species is largely in its infancy.
   b. ICES should actively promote, as a high research priority, further studies on the effects of climate change and ocean acidification on commercially cultured shellfish species, and particularly their sensitive early life stages. Research priorities include 1) determine sensitivities to perturbations under ecologically relevant conditions; 2) identification of the cumulative effects of warming and acidification; 3) assess the capacity of key species to acclimate and/or genetically adapt to related modifications of their environment; 4) given that climate change scenarios vary across ICES countries, assess regional susceptibilities for aquaculture impacts and the socio-economic consequences; 5) development of decision-making processes for mitigation of shellfish aquaculture impacts and a proactive strategy for adaptation.

9) Site selection criteria in molluscan aquaculture with particular reference to accessing and developing offshore facilities
   a. WGMASC should initiate a focused effort to identify the best offshore production concepts,
   b. Rethink the logistics in relation to processing and transport to the market;
   c. In the next decade an increasing high numbers of marine windparks will be established in off shore areas. The windparks may potentially support a production of bivalves. WGMASC should initiate an analysis of the poten-tial for bivalve aquaculture in windparks. The analysis should focus on blue mussels, but also include other shellfish species.

1.4.3 References

ICES. 2003. Report of the Working Group on Marine Shellfish Culture (WGMASC), 13–15 August 2003, Trondheim, Norway. ICES CM 2003/F:05. 50 pp.

ICES. 2004. Report of the Working Group on Marine Shellfish Culture (WGMASC), 3–15 May 2004, Portland, Maine ICES CM 2004/F:05. 55 pp.

ICES. 2005. Report of the Working Group onMarine Shellfish Culture (WGMASC), 13–15 May, La Rochelle, France. ICES CM 2005/F:05. 74 pp.

ICES. 2006. Report of the Working Group on Marine Shellfish Culture (WGMASC), 18-20 April, Galway, Ireland. ICES CM 2006/MCC:02. 39 pp.

ICES. 2007. Report of the Working Group on Marine Shellfish Culture (WGMASC), 27-29 March 2007, Halifax, Canada. ICES CM 2007/MCC:01. 80 pp.

ICES. 2008. Report of the Working Group on Marine Shellfish Culture (WGMASC), 1–3 April 2008, Aberdeen, UK. ICES CM 2008/MCC:02. 71 pp.

ICES. 2009. Report of the Working Group on Marine Shellfish Culture (WGMASC), 7–9 April 2009, Bremerhaven, Germany. ICES CM 2009/MCC:02. 91 pp.

ICES. 2010. Report of the Working Group on Marine Shellfish Culture (WGMASC), 29 March–2 April 2010, Galway, Ireland. ICES CM 2010/SSGHIE:07 . 94 pp.

ICES. 2011. Report of the Working Group on Marine Shellfish Culture (WGMASC), 5–8 April 2011, La Trinité-sur-Mer, France. ICES CM 2011/SSGHIE:08. 92 pp.

ICES. 2012. Report of the Working Group on Marine Shellfish Culture (WGMASC), 20–23 March, Sopot, Poland. ICES CM 2012/SSGHIE:15. 117 pp.

1.5 ICES Working Group on Application of Genetics in Fisheries and Mariculture (WGAGFM)

Table 1.5. Aquaculture related topics from the ICES Working Group on Application of Genetics in Fisheries and Mariculture (WGAGFM).

Year	Topic
2006	1. Genetic basis of domestication processes in farmed fish and shellfish
	2. Genetic effects of the introgression of farmed Atlantic salmon on wild salmon populations
2007	3. Potential application of genomics in fisheries management and aquaculture genetic and spatial data analysis methods for resolving spatial boundaries of finfish and shellfish populations, and for gaining insight into the geographic and ecological factors controlling the development of population boundaries
2008	4. Current and future prospects of QTL-based studies in fisheries and aquaculture

2009	5. Update and insights from the EU project SALSEA-Merge on establishment of a large-scale genetic database for assigning individual to population of origin
2010	6. Pursuing the establishment of a meta-database cataloguing molecular data in the field of fish and shellfish population genetics
	7. interaction of marine escaped farmed finfish on wild fish populations at a local and regional scale, and specific aspects for reducing uncertainty in risk assessment
	8. potential for using parasites, microbes and viruses as "magnifying glass" for fish stock characterisation
2012	9. use of adaptive SNPs and other adaptive markers for genetic identification of populations (breeding stocks)
2013, 2014	10. identification and use of adaptive gene markers in shellfish aquaculture and for the genetic characterization of wild populations – issues and solutions
2014	11. Quantifying the presence and impact of domesticated Atlantic salmon in the wild: approaches and strategies for studying introgression
	12. Request from OSPAR: "genetic impacts on marine environment and on wild fish stocks, specifically in connection with introgression of foreign genes, from both hatchery-reared fish and genetically modified fish and invertebrates, in wild populations"

1.5.1 Summary of WGAGFM advice/recommendations related to aquaculture topics:

1) Genetic basis of domestication processes in farmed fish and shellfish Hatchery impact on shellfish production, application of genetic tools and genetic consequences on natural populations.
    - To promote studies on unintentional natural selection to understand the process of domestication and more experiments demonstrating the change and the genetic basis of such traits
    - To genetically monitor hatching of fish/shellfish to be used for sea-ranching, aquaculture based fisheries or restocking purposes and to carefully estimate unintentional selection occurring during captivity.
    - To be aware of the unintentional selection going on in the hatcheries, which can/may have implications/potential effect on the wild population or induce further domestication.

- To engage in more research regarding gene expression analysis for further understanding the nature of the genetic changes associated with domestication.

2) Genetic effects of the introgression of farmed Atlantic salmon on wild salmon populations.
    - The Guidelines on Containment of Farm Salmon, developed by the North Atlantic Farming Industry and the North Atlantic Salmon Conservation Organization (NASCO) should be the minimum standard for the construction and operation of fish farms. Research into further improving both technological and operation standards should be undertaken.
    - Smolt rearing units should not outflow into salmon rivers (as already required in Norway).
    - Marine cages should not be situated within 30km of salmon rivers.
    - Where escapes occur, appropriate recovery plans and resources should be available for immediate deployment.
    - Further investigations in the use of triploids and other bioconfinement methods should be undertaken.
    - If it is intended to introduce sterile transgenic salmon in the industry in the future, research should be undertaken prior to permission being granted, to determine the ecological impact that such fish may have on wild populations.
    - Building of realistic working simulation models, which can be used to assess risks of direct genetic interactions, which can be used to identify research priorities.
    - Research into indirect genetic and ecological impacts associated with issues such as introduction disease and effects of density dependent population dynamics.
    - Spatial and temporal studies.

3) Potential application of genomics in fisheries management and aquaculture genetic and spatial data analysis methods for resolving spatial boundaries of finfish and shellfish.
    - The implementation of genomic approaches should be encouraged in the fields of fisheries and aquaculture by supporting the development of genomic resources, such as BAC libraries, fine scale linkage maps, EST databases and expression profiling.
    - International networks and large collaborative initiatives are essential so that projects such as full genome sequencing can be implemented and be exploited in various fields of fisheries and aquaculture.
    - Open access web-based resources, joining available genomic data (ESTs, mapping data, BAC fingerprinting and annotation…) should be developed in order to favour integrated collaborations (see also topic 4).

- Studies of local adaptations in the wild and hatchery populations should incorporate genomic approaches to further understand the footprints of selection at a genome wide level.
- Potentials of molecular marker assisted selection and domestication process in aquaculture species should be further explored, benefiting from the development of new genomic resources and computational and analytical tools.

4) Populations, and for gaining insight into the geographic and ecological factors controlling the development of population boundaries.
    - Before starting a sampling programme for a particular species we recommend that all available information on biological and physical parameters, including geographical features, hydrographical data and geological information, be taken into consideration. In terms of biological parameters we need information such as: migration pattern, spawning areas, extent of philopatry, spawning time, feeding grounds, growth rate, natural and fishing mortality.
    - In order to compare genetic and geographic information it is necessary to identify stage in the life cycle where populations are most discrete. This will generally be the spawning stage. We recommend that an optimal sampling strategy be devised, depending on the species
    - We recommend using the most appropriate molecular methods in a comprehensive spatial survey, incorporating as far as possible a temporal component.
    - It is recommended that genetic and geographic information be combined using the most appropriate landscape genetics approaches, eg, currently BARRIER and AIS.
    - We recommend attempting to explain results from landscape genetics software in terms of available physical and biological information in order to improve predictive capacity and make best use of the results of analysis.
    - To delineate the spatial extent of each population using survey, we recommend using both physical and genetic data.
    - Having defined populations that at other stages of the life cycle where population mixing may occur we recommend that approaches based on MSA/IA be used to estimate proportions in the mixture and population identity of individual animals.
    - As an overarching recommendation, given that methods are now available for many species of identifying structuring into breeding populations, it is recommended to fisheries managers that these methods be used in conjunction with geographical information systems to define the spatial and temporal 'footprint' of these breeding populations in order to allow population focused management.
    - We recommend that future work involve further investigations of the relationship between geographical information and population genetics, so that

maximal use can be made of the synergy between these two fast developing fields.

5) Current and future prospects of QTL-based studies in fisheries and aquaculture.
    - QTL studies should be supported in both in wild and farmed aquatic species as they are one of the most direct ways to understand the genetic basis of phenotypic variation, linking classic quantitative genetic and genomic studies.
    - QTL studies should not be restricted to MAS. The development of QTL studies should be supported as they can also contribute to a better understanding of the genetic architecture of adaptive traits of interest to fisheries and their management.
    - To aid identification of QTL in a wider variety of aquatic species, the current development of genomic resources - notably linkage and physical maps, EST and BAC libraries and whole genome sequences - should be encouraged.
    - The development of statistical methods and software adapted to aquatic species should be supported to facilitate the development of linkage maps and to identify QTLs.
    - The development and maintenance of divergent lines, segregating progenies, or other biological material of interest for QTL mapping should be encouraged.

6) Update and insights from the EU project SALSEA-Merge on establishment of a large-scale genetic database for assigning individual to population of origin.
    - Support and promote extension of the SALSEA-merge database for European Atlantic salmon stocks to encompass stocks in the Western Atlantic.
    - Support endeavours to extend work on the use of genetic markers to advance understanding of the marine ecology of Atlantic salmon beyond the life of the existing EU SALSEA-Merge project.
    - Review the potential of use molecular genetic markers in other marine species under ICES remit for monitoring spatial and temporal movements of individuals, populations and stocks to advance understanding of their marine ecology

7) Pursuing the establishment of a meta-database cataloguing molecular data in the field of fish and shellfish population genetics.
    - A working demonstration meta-database of molecular population genetic information be developed for the Atlantic salmon, building on the EU SALSEA Merge project, to assess the benefits, feasibility and practical operational issues of developing a full, multi-species meta-database.

8) Interaction of marine escaped farmed finfish on wild fish populations at a local and regional scale, and specific aspects for reducing uncertainty in risk assessment.

- the collection of basic biology knowledge about new candidate and establish species in aquaculture; behaviour and reproduction;
- that research be supported to provide information related to risk assessment to the following production technologies; sterile fish, local brood-stock, cage technology;
- that a review on "lessons learned" from other more established farmed species (agriculture and aquaculture) is carried out;
- that a genetic inventory of wild populations of target species is undertaken.

9) Potential for using parasites, microbes and viruses as "magnifying glass" for fish stock characterisation.
   - It is recommended, given that parasite population genetics can be a proxy for identifying host fish populations (including farmed and native groups), make good use of it, when appropriate for the research question addressed. This requires promoting interdisciplinary interaction between fish biologists, fisheries scientist, ecologists, evolutionary biologists, parasitologists, bacteriologists and virologists in order to enhance parasite supported stock.

10) Use of adaptive SNPs and other adaptive markers for genetic identification of populations (breeding stocks).
   - That genetic markers under directional selection continue to be identified and employed in genetic stock identification analysis as such markers have been shown to yield informative insights on both the scale and dynamics of populations and in identifying potential underlying drivers.

11) Identification and use of adaptive gene markers in shellfish aquaculture and for the genetic characterization of wild populations – issues and solutions.
   - Cases/scenarios where interactions between shellfish of mariculture and wild origin is of concern genomic tools may allow estimation of potential introgression.
   - Recent developments in genetic screening techniques (e.g. Next-Generation Sequencing and genome sequencing) promise great power to identify markers linked to traits of interest and the incorporation of such techniques should be encouraged in the shellfish aquaculture context.

12) Quantifying the presence and impact of domesticated Atlantic salmon in the wild: approaches and strategies for studying introgression
   - At present, the largest challenge in the resolution of genetic impacts from farmed escape Atlantic salmon on wild populations seems to remain the identification of recent hybrids (F1) and recent introgression (F2, Backcrosses).
   - It is critical that during the implementation of highly selective SNP panels and genome wide analysis, simulation studies continue to be used to provide robust evaluations of accuracy, and identify limitations.

13) Request from OSPAR: "genetic impacts on marine environment and on wild fish stocks, specifically in connection with introgression of foreign genes, from both hatchery-reared fish and genetically modified fish and invertebrates, in wild populations"
    - Ongoing genetic marker based developments in other species (sea bream, sea bass, turbot) are expected to facilitate implementation of monitoring to determine degrees and effects of farm-wild hybridization and introgression, ranging from local to global geographical scales.
    - It is highly recommended that risk assessments be conducted incorporating genetic considerations, from which management plans can be developed.

1.5.2 References

ICES. 2006. Report of the Working Group on the Application of Genetics in Fisheries and Mariculture (WGAGFM), 24–27 March 2006, Newport, Ireland. ICES CM 2006/MCC:04. 59 pp.

ICES. 2007. Report of the Working Group on the Application of Genetics in Fisheries and Mariculture (WGAGFM), 19-23 March 2007, Ispra, Italy. ICES CM 2007/MCC:03. 70 pp.

ICES. 2008. Report of the Working Group on the Application of Genetics in Fisheries and Mariculture (WGAGFM), 1–4 April 2008, Pitlochry, Scotland, UK. ICES CM 2008/MCC:04. 77 pp.

ICES. 2009. Report of the Working Group on the Application of Genetics in Fisheries and Mariculture (WGAGFM), 1–3 April 2009, Sopot, Poland. ICES CM 2009/MCC:03. 74 pp.

ICES. 2010. Report of the Working Group on the Application of Genetics in Fisheries and Mariculture (WGAGFM), 5–7 May 2010, Cork, Ireland. CM2010/SSGHIE:12. 51 pp.

ICES. 2011. Report of the Working Group on the Application of Genetics in Fisheries and Mariculture (WGAGFM), 4-6 May 2011, Bangor, United Kingdom. ICES CM 2011/SSGHIE:13. 82pp.

ICES. 2012. Report of the Working Group on the Application of Genetics in Fisheries and Mariculture (WGAGFM), 2-4 May 2012, Derio, Spain. ICES CM 2012/SSGHIE:12. 61 pp.

ICES. 2013. Report of the Working Group on the Application of Genetics in Fisheries and Mariculture (WGAGFM), 7–9 May 2013, Reykjavik, Iceland. ICES CM 2013/SSGHIE:11. 48 pp.

ICES. 2014. Report of the Working Group on the Application of Genetics in Fisheries and Mariculture (WGAGFM), 7–9 May 2014, Olhão, Portugal. ICES CM 2014/SSGHIE:13. 79 pp.

1.6 ICES Working Group on Environmental Interactions of Mariculture (WGEIM)

Table 1.6. Aquaculture related topics from the Working Group on Environmental Interactions of Mariculture (WGEIM).

Topic	2002	2003	2004	2005	2006
1	Issues of environmental impact, sustainability and technological change				
2	Diversify production through new species				
3	Offshore farming				
4	Alternate protein and lipid use				Fish feed
5	Assess the relationships between WFD targets and aquaculture requirements.				
6		Potential impact of escaped non-salmonid aquaculture candidates on local stocks			
7			Sea lice Treatment		
8				Evaluate examples of sustainability indices proposed for mariculture operations and provide specific recommendations on utility of proposed	
9				The current state of development of integrated culture systems (IMTA) with a view to assessing the potential of polyculture to mitigate the environmental effects of mariculture	

Table 1.7. Aquaculture related topics from the Working Group on Environmental Interactions of Mariculture (WGEIM) (continued).

Topic	2007	2008	2009	2010	2011	2012
4		Feed use				
7						Treatment of sea lice – well boats
8	Evaluate examples of sustainability indices proposed for mariculture operations and provide specific recommendations on utility of proposed					
9	The current state of development of integrated culture systems (IMTA) with a view to assessing the potential of polyculture to mitigate the environmental effects of mariculture					
10		Climate change and Aquaculture				
11		Fouling hazards				
12				Effects of mariculture on wild fish (OSPAR request)		

1.6.1 Summary of WGEIM publications on aquaculture topics

Black E. A. and I.M. Davies, 2008. Introduction. In: IMO/FAO/UNESCO-IOC/WMO/IAEA/UN/UNEP/UNIDO Joint Group of Experts on Scientific Aspects of Marine Environmental Protection (GESAMP) 2007. Assessment and communication of environmental risks in coastal aquaculture. Rome, FAO. GESAMP Reports and Studies (76): 200p.

Davies I.M. and E.A. Black, 2008. Environmental effects, risks and uncertainties associated with coastal aquaculture. In: IMO/FAO/UNESCO-IOC/WMO/IAEA/UN/UNEP/UNIDO Joint Group of Experts on Scientific Aspects of Marine Environmental Protection (GESAMP) 2007. Assessment and communication of environmental risks in coastal aquaculture. Rome, FAO. GESAMP Reports and Studies (76): 200p.

Black E.A. and I. M. Davies, 2008. Risk analysis. In: IMO/FAO/UNESCO-IOC/WMO/IAEA/UN/UNEP/UNIDO Joint Group of Experts on Scientific Aspects of Marine Environmental Protection (GESAMP) 2007. Assessment and communication of environmental risks in coastal aquaculture. Rome, FAO. GESAMP Reports and Studies (76): 200p.

Black E. A. and I.M. Davies, 2008. Risk analysis in practice for coastal aquaculture. In: IMO/FAO/UNESCO-IOC/WMO/IAEA/UN/UNEP/UNIDO Joint Group of Experts on Scientific Aspects of Marine Environmental Protection (GESAMP) 2007. Assessment and communication of environmental risks in coastal aquaculture. Rome, FAO. GESAMP Reports and Studies (76): 200p.

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Haya, K., Burridge, L., Davies, I., & Ervik, A. (2005). A review and assessment of environmental risk of chemicals used for the treatment of sea lice infestations of cultured salmon. In Hargrave B (ed) Environmental effects of marine finfish aquaculture. Springer, Berlin. p 305-340.

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

McKindsey CW, Landry T, O'Beirn FX, Davies IM (2007) Bivalve aquaculture and exotic species: a review of ecological considerations and management issues. Journal of Shellfish Research 26: 281–294.

O'Beirn FX, McKindsey CW, Landry T, Costa-Pierce B (2012) Methods for sustainable shellfish culture. In: Meyers RA (ed) Encyclopedia of Sustainability Science and Technology. Reference Editorial Office, Springer, p 9174-9196

1.6.2 Summary of WG advice/recommendations on aquaculture topics by topic:

1) Review issues of environmental impact, sustainability and technological change in mariculture:

    a. In order to foster a sustainable development of coastal and marine aquaculture, there is a need to diversify production and to cultivate new species. A pro-active approach is required to avoid mistakes made previously when salmonid farming was developing. Mitigation strategies based on sound scientific criteria in relation to the species under consideration need to be prepared at an early stage of development. Studies would have to consider the status of the natural stocks in the area, the potential genetic, trophic and behavioural interactions, and, foremost and specifically, the development of methods for recovery of escaped fish in the event of large-scale escapements. This subject seems to be of particular importance for non-migratory fish stocks with small localized populations (e.g., sea bass and seabream), or migratory species with different migratory patterns than salmonids (e.g., cod, halibut, turbot, and wolffish and other species).

b. MARAQUA project, recommended that in some instances environmental studies of a more limited nature could be carried out and the results provided to the regulatory authorities in the form of an "Environmental Report" when making an application for a shellfish farming permit. The WGEIM noted that the preparation of such reports should ideally be done on a case-by-case basis and the information should be relevant to the specific site and local conditions.

c. WGEIM considered that the cumulative impacts of many small operations could be significant and that appropriate management and regulatory strategies need to be developed to minimise these impacts. Such strategies will require the development of carrying capacity models, and the setting of Environmental Quality Objectives (EQO) and Environmental Quality Standards (EQS), which ideally should be part of a science-based Integrated Coastal Zone Management system.

d. A number of technologies and support systems are presently under development, some of which have been outlined in the WGEIM 2002 Report. These should be evaluated and compared, with the aim to prepare a review publication on the requirements for a DSS system tailored to the needs of mariculture that builds on the state of the art and/or links to existing systems.

2) Assess the relationships between the Water Frame Directive (WFD) targets and the requirements of aquaculture.

a. As the targets for improvements in water quality will be defined within the WFD system, it is important to assess the relationships between the WFD targets and the requirements of aquaculture.

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

3) Offshore farming

a. Member Countries support research on the performance of new offshore farming systems and on the operational risks and environmental interactions associated with such new farming systems. The Mariculture Committee should through its national members foster the collection of information on national activities in this area to be considered by the working group during the next meeting.

   b. Although offshore farming systems are presently under development and several are already being used on a trial basis, there is a long learning process ahead in the needs of the infrastructure for operating such systems. Even though being mainly distant from the coast, there is a need for a land base and for support systems that may require specific developments and control measures to prevent unforeseen hazards. Are the automated monitoring tools presently available adequate to safeguard offshore systems? What control measures and rescue strategies and options exist in extreme situations? Besides these technical aspects, there are a number of biological factors that may be operating at different levels than in inshore farms (e.g., behavioural aspects, biotechnology of sorting, application of counting and measuring techniques, monitoring for mortalities and their recovery, etc.

   c. A number of technologies and support systems are presently under development, some of which have been outlined in the WGEIM 2002 Report. These should be evaluated and compared, with the aim to prepare a review publication on the requirements for a DSS system tailored to the needs of mariculture that builds on the state of the art and/or links to existing systems

4) Alternate use of protein and oil/ Fish feed/ Feed use

   a. The high prices and the lack of opportunities to expand the capture fishery make it imperative that alternate protein and lipid sources be developed for use in aquafeeds.

   b. The main recommendation is that during the intersession (from 2006), WGEIM lead a review and evaluation of recent advances on alternative sources of lipid and protein to fish oil and fish meal in aquafeed. It is proposed that a WGEIM review a draft manuscript at the 2007 meeting that is to be submitted for publication in a peer reviewed scientific journal.
   c. WGEIM to provide an update on fin fish feed usage and constituents from member countries to include in the meeting report in 2009.

5) Potential impact of escaped non-salmonid aquaculture candidates on local stocks.

   a. Monitoring for sexual maturity and spawning activities should be carried out on farms that rear cod beyond the normal age of sexual maturity (two years) and be available in aggregate for the industry. Such monitoring might assist in addressing the question of whether photoperiod manipulation is effective in delaying sexual maturation and identify where the potential risk of egg releases could occur. The potential to recapture escaped cod has not been analysed; but is an important area for Research.

b. Studies to determine the survival of escapees, their migration patterns in relation to their location (e.g. inshore or offshore) and the season they are released. The impact of releases in summer may be different from winter, when sea bass are not feeding intensively but are reproducing.
    i. Development of tools to distinguish wild fish from escapees.
    ii. Better information on the structure and habitat use of wild populations.
    iii. Development of offshore systems to reduce interactions with inshore wild populations.
    iv. Monitoring the behaviour of adults and juveniles released in offshore locations. It would be especially helpful to invest in this type of research now, before the
    v. cultured stock used by industry has had time to further genetically differentiate from local stocks.
    vi. The efficacy of photoperiod control on maturation.
    vii. Another possible approach, not specific to sea bass, could be to produce fish that genetically do not synthesize some essential dietary component which they can only find in artificial feed. This would make the fish unable to survive in the wild. However this solution is highly hypothetical and needs substantial theoretical development (animal welfare, technical feasibility) but could also be applied to GMO fish if they are adopted by the industry.
    viii. One way to decrease the impact of releases in a given environment would be to maximise the wild stocks in areas where farming activities are based, particularly where wild stocks are scarce. This would require tools to be available to evaluate these wild stocks.
    ix. Tools to enable the recognition of wild fish from escapees are not readily available, and new developments are necessary to implement their monitoring.

6) Evaluate examples of sustainability indices proposed for mariculture operations and provide specific recommendations on utility of proposed.

a. Management of aquaculture activities in marine systems is dependent upon a number of broad principles.
    i. All activities carried out in the marine environment will impact on the system in some fashion
    ii. These impacts can be measured at some scale be it global, regional and local;
    iii. The determination of ecological thresholds relating to impact can be informed by scientific investigation; and

iv. Ultimately the level of impact permitted is a policy decision made by managers and informed by societal values.

b. The establishment of thresholds relating to specific indicators is an important consideration when determining the ecological tolerance of the system to perturbations. Impact indicators have some capacity to measure habitat resilience and recoverability. Coupled with scenario building, ecosystem modelling provides a mechanism to explore resilience and tipping points in habitats and ecosystems.

c. 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.

d. 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).

7) Treatment of sea lice

a. A risk management approach should be used to determine treatment strategies.

b. The ecological risk of the sea lice therapeutants were assessed by reviewing information on their distribution and persistence in the marine environment, their biological effects observed on marine organisms in laboratory and field studies, and the likelihood that these biological effects would occur during the use of these chemicals to treat sea lice infestations of cultured salmon.

c. Although near- and far-field effects may be anticipated, there is great variation among species and chemical compounds and a paucity of data to predict how effects may be manifest.

d. Site-specific factors (hydrological and biological) are likely of great importance.

e. (2012) Guidance on assessment of the risks associated with discharges from mobile well-boats and cost effective solutions to reduce the discharged quantities of lice or treat-ments 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.

8) Evaluate examples of sustainability indices (that take social values into consideration (2012)) proposed for mariculture operations and provide specific recommendations on utility of proposed.

    a. Appropriate decision support systems (DSS) should consider the spatio-temporal requirements of mariculture together with the requirements of other activities.

    b. The issues of sustainability of mariculture and sustainability indices have been addressed by the WGEIM, WGMASC, and other EGs and groups for a number of years. Reviews mostly focus on "impact indicators" whereas "sustainability indicators" also include social factors, including what is deemed to be "acceptable" by various stakeholders. These latter indices also include other activities within a given area within the context of ICZM.

    c. All activities should be considered when licensing activities in a system, i.e. both positive and negative aspects must be measured.

    d. (2012) 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 and Socio- Economic Dimensions of Aquaculture (SGSA).

9) The state of development of integrated culture systems (IMTA) with a view to assessing the potential of polyculture to mitigate the environmental effects of mariculture
    a. Review of existing Integrated Multi-Trophic Aquaculture IMTA programs and specific projects continues as a Term of Reference for WGEIM 2009. In addition it is proposed to expand this ToR in order to address the issue of energy and nutrient cycling associated with IMTA systems and report in 2009.
    b. (2012) Issues relating to multi-trophic aquaculture remain an active EG theme to address issues raised in the current document. This includes (but is not limited to) issues relating to ocean ranching of echinoderms.
10) Climate change and Aquaculture
    a. Assessing the potential impact of climate change on aquaculture activities is a useful scenario setting exercise that might be conducted in all member states involved in marine aquaculture.
11) Fouling hazards
    a. Continue to investigate fouling hazards associated with the physical structures used in mariculture with a view to developing integrated pest

management strategy using case studies from Canada and Spain and report in 2009.

b. To define the types of information that is needed to develop an integrated pest management strategy.

c. Overview of the types of information needed to establish an integrated pest management strategy for tunicates in bivalve aquaculture. A comparison of the situation in Spain (Galicia) and eastern Canada (Prince Edward Island) is given to contrast two situations with different levels of infestation (PEI > Galicia, using *Ciona intestinalis* as a target species) to suggest insights into potential explanations for the observed differences in tunicate loads.

d. Fouling hazards and integrated pest management strategies should 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.

12) Effects of mariculture on wild fish (OSPAR request 2010/3)
   a. The risk assessment is visualised in table 4.4.1.of the report ICES CM 2010/SSGHIE:08. Use of fish for feed is the only component analysed that has a high risk of impacting wild stocks in this analysis.

1.6.3 References

ICES. 2002. Report of the Working Group on Environmental Interactions of Mariculture (WGEIM), 8–12 April 2002, ICES Headquarters, Denmark. ICES CM 2002/F:04 101 pp.

ICES. 2003. Report of the Working Group on Environmental Interactions of Mariculture (WGEIM), 31 March –4 April 200, Vigo, Spain. ICES CM 2003/F:04 114 pp.

ICES. 2004. Report of the Working Group on Environmental Interactions of Mariculture (WGEIM), 8–12 April 2004, Galway, Ireland. ICES CM 2004/F:02 100 pp.

ICES. 2005. Report of the Working Group on Environmental Interactions of Mariculture (WGEIM), 11–15 April 2005, Ottawa, Canada. ICES CM 2005/F:04 116 pp.

ICES. 2006. Report of the Working Group on Environmental Interactions of Mariculture (WGEIM), 24–28 April 2002, Narragansett, Rhode Island, USA. ICES CM 2006/MCC:03 201 pp.

ICES. 2007. Report of the Working Group on Environmental Interactions of Mariculture (WGEIM), 16–20 April 2007, Kiel, Germany. ICES CM 2007/MCC:02 64 pp.

ICES. 2008. Report of the Working Group on Environmental Interactions of Mariculture (WGEIM), 14–18 April 2008, Victoria, B.C. Canada. ICES CM 2008/MCC:03 61 pp.

ICES. 2010. Report of the Working Group on Environmental Interactions of Mariculture (WGEIM), 29 March–2 April 2010, Galway, Ireland. ICES CM 2010/SSGHIE:08 68 pp.

ICES. 2012. Report of the Working Group on Environmental Interactions of Mariculture (WGEIM), 20–23 March 2012, Sopot, Poland. ICES CM 2012/SSGHIE:16 59 pp.

1.7 ICES Working Group on Pathology and Diseases of Marine Organisms

Table 1.8. Aquaculture related topics from the Working Group on Pathology and Diseases of Marine Organisms (WGPDMO).

Topic	2005	2008	2009	2010	2011	2012	2013	2014
1	National reports on disease and new disease trends (for Mariculture for instance HSMI, VHS, ISA, fransicella and sea lice)							
2	Fish disease index (FDI)							
3	Sea lice / disease interaction between farmed and wild fish							
4	Disease in bivalves							
5		International collaboration and networks						
6				Disease modelling wild and farmed fish				
7							Parasites and other infectious agents in marine finfish and shellfish species posing a hazard to human health	
8								Special request: interactions between wild and captive fish stocks (OSPAR 4/2014

1.7.1 Summary of WGPDMO publications on aquaculture topics

Murray, A. G. 2008. Existing and potential use of models in the control and prevention of dis-ease emergencies affecting aquatic animals. Rev. sci. tech. Off. int. Epiz., 27(1): 211–228.

1.7.2 Summary of WGPDMO outputs on aquaculture topics

2005:

- A number of new disease trends in wild and farmed fish and shellfish was reported by Member Countries for 2004.
    - Heart and skeletal muscle inflammation (HSMI) is a major and increasing disease problem for Norwegian Atlantic salmon aquaculture.
    - According to a review on the role of plankton in gill-related mortality in farmed fish in contact with planktonic organisms (e.g. jellyfish) may result in mass mortality in farmed Atlantic salmon (*Salmo salar*).
- Due to multiple factors influencing wild fish populations, no firm conclusions can yet be drawn regarding the extent of sea lice interactions between farmed and wild fish and the effect on wild salmon.

2008:

- Heart and Skeletal Muscle Inflammation and Pancreas Disease continue to show an increasing trend in Norway. HSMI was seen for the first time in freshwater fish. PD remains endemic in Irish salmon farms.
- A swarm of the jellyfish, *Pelagia noctiluca*, caused for the first time 100% mortality at an Atlantic salmon farm in Northern Ireland.
- Review the information on Francisella sp. and visceral granulomatosis in farmed cod and the potential for disease interaction between wild and farmed cod.
- Review the evidence for increased tolerance by *Lepeophtheirus salmonis* to chemotherapeutants:-1) Treatment of sea lice can be effective but this is costly and access to efficacious medicines and pesticides is limited to a small number of available compounds and by regional or national regulatory processes. 2) The limited available information provides evidence of increased parasite tolerance to four classes of compounds: organophosphates, pyrethroids, hydrogen peroxide and avermectins.
- WGPDMO noted that there is an increasing number of international collaborative actions involving fish and shellfish disease and pathology, reflecting the importance of disease issues in relation to environmental monitoring and assessment as well as to mariculture.

2009:

- Overview of diagnosed viral cases in Norwegian salmonid farms of viral haemorrhagic septicaemia (VHS), infectious salmon anaemia (ISA), infectious pancreatic necrosis (IPN), salmonid alphavirus (SAV), heart and skeletal muscle inflammation (HSMI) for the period 1999–2008.
- The first outbreak of IHN in The Netherlands occurred in a rainbow troutfarm.
- Salmonid alphavirus infection is a cause of significant losses in farmed Atlanticsalmon in Ireland, Norway and Scotland.
- Repeated treatment failures have led to the suspicion of multi-resistance ina salmon louse population against several compounds used for oral and bath treatment in Norway.
- Francisellosis has continued to increase in Norway since it was first detectedin 2004 and is considered the most significant disease on cod farms.
- Gill disorder remains a serious problem on Irish salmon farms. It is considered to be a multifactorial disorder and a research programme has been initiated to investigate the problem.

2010:

- National reports: Wild & Farmed fish and shellfish (molluscs and crustaceans) PD decreasing in Norway, IPN increasing in Norway; Francisella found in cod in Ireland; Sea lice numbers increasing in Norway & USA, evidence of resistance development.
- Summarise the current state of knowledge on parasite interactions from finfish mariculture on the condition of wild fish populations (both salmonid and non-salmonid) both at a local and regional scale.

2011:

- L. Salmonis (salmon lice) is considered the biggest threat to marine survival of salmonids

2012:

- Review of occurrence and mitigation of pathogen transfers from mariculture fish to wild populations.

2013:

- The issue of sea lice infestations on wild salmonids is an area of increasing concern. In relation to farmed fish, amoebic gill disease has emerged as a major issue for Atlantic salmon farming in Ireland and Scotland. Pancreas disease (PD) caused by the salmonid alphavirus subtype 2 is also spreading in Norway, previously PD in Norway was only caused by subtype 3. For farmed shell-fish, a new host species for Bonamia exitiosa was identified in the US and Vibrio aestuarianus has been linked to increased mortalities in Pacific oysters in Europe.

- Along the Northwest coast of Ireland, a dinoflagellate bloom (*Karenia mikimotoi*) was reported in July and was associated with 60-100% mortality in both Pacific and European flat oysters.

2014:

- Norway has reported a 50% decline in the number of cases of infectious pancre-atic necrosis, believed to be due to eradication of IPN virus in hatcheries along with the use of selective breeding for resistance to the disease. Amoebic gill disease, which is now endemic on marine Atlantic salmon farms in Ireland and Scotland, is spreading in Norway. The disease has also been reported in cleaner fish which are increasingly used as a biological control for sea lice.

1.7.3 Summary of WG advice/recommendations on aquaculture topics:

2005:

- Available new information on the causes and effects of heart and skeletal muscle inflammation (HSMI) affecting farmed Atlantic salmon (*Salmo salar*) in ICES Member Countries are reviewed by WGPDMO for the 2006 meeting.

2008:

- Fish disease monitoring data will be useful in evaluating the effects of climate change on fish health and provide better understanding of pathogen interactions between wild and farmed fish.
- ICES member countries conduct further research to refine diagnostic tools and to develop treatments or vaccines for francisellosis in farmed cod.
- ICES Member Countries i) encourage research to identify and license new classes of sea lice medications; ii) encourage salmon aquaculture companies to practise integrated pest management, including synchronised treatments within management areas, use of alternating classes of sea lice medication, and routine sea lice monitoring; iii)encourage coordinated use of bioassay techniques to screen for tolerance to medicines and pesticides;
- Communication networks of diagnostic practitioners and internationally recognised experts in aquatic animal health in ICES Member countries be established and maintained.

2009:

- WGPDMO Members are encouraged to provide information on diseases in farmed fish using the new standards and guidelines.

- Francisellosis should be followed and new information about outbreaks, diagnostic improvements, host susceptibility and further developments in vaccine production should be included in the national reports.

2010:

- In order to reduce the risk of sea lice interactions between farmed and wild fish, ICES member countries:
  - Recommend to establish salmon mariculture production thresholds, based on capacity to produce salmon louse larvae, in coastal ecosystems presently or potentially occupied by salmon mariculture.
  - Encourage and support the development of hydrodynamic and particle tracking modelling studies of coastal ecosystems presently or potentially occupied by salmon mariculture and other types of mariculture.
  - Support the development of measures to reduce the risk associated with salmon lice interaction between farmed and wild fish by developing novel efficient and environmentally-safe therapeutants, vaccines and technical measures such as barriers between farms and the environment.
  - Should establish and maintain systematic monitoring programmes of salmon lice on salmonids in coastal areas with, or likely to have, salmon mariculture.
- In light of the expanding mariculture industry, ICES member countries should enhance research and monitoring activities addressing interactions between other fish and shellfish species and other diseases and parasites, including potential population effects.

2011:

- It is important to use disease monitoring data in wild populations to provide baseline data prior to cultivation/ mariculture activities.

2012:

- WGPDMO recommend renewed contact with WGEIM (now WGAQUA)

2013:

- Five new ICES Identification Leaflets for Diseases and Parasites of Fish and Shellfish were published and are available on the ICES website.
- The potential effects of sea lice infestations on wild salmonid populations is an area of concern for both the aquaculture and wild fishery sectors and WGPDMO are currently looking at this issue (ToR c and ToR g).
- ICES Member Countries should be aware of the emergence of Vibrio aestuarianus as an important pathogen of Pacific oysters which should be monitored.
- Provide expert knowledge and advice on fish disease and related data to the ICES Data Centre.

2014:

- Two new ICES Identification Leaflets for Diseases and Parasites of Fish and Shellfish were published and are available on the ICES website.
- The WGPDMO noted with concern that some ICES member countries have not provided sufficient resources to support wild fish monitoring programmes, resulting in an insufficient spatial and temporal coverage of fish populations. It was emphasised that this lack of data will affect marine ecosystem health assessments in national and international programmes (e.g. under the EU Marine Strategy Framework Directive, OSPAR Coordinated Environmental Monitoring Programme (CEMP), and revised HELCOM monitoring programme). Additionally, there is a risk that emerging disease conditions affecting marine fish will not be detected.
- The following management actions in mariculture are expected to mitigate pathogen transmission between farmed and wild salmonid populations:
  1) Systematic collection of disease-relevant data including pathogen identification, prevalence, severity, mortality;
  2) Systematic collection of data related to farm species and biomass, seawater temperature and salinity and plankton density;
  3) Archive data in an accessible format. Establish data sharing protocols;
  4) Develop and apply circulation models to characterise hydrographic pro-cesses in mariculture coastal zones to estimate pathogen dispersion from farms or farm clusters;
  5) For each farm or farm cluster, establish management zones, defined on lo-cal hydrography and biological properties of infectious agents. Manage-ment zones should incorporate limits to local biomass, and protocols for coordinated activities such as stocking, disease pathogen monitoring, har-vesting, single age-class, sea lice treatments.
  6) Whenever feasible, conduct pathogen surveillance of adjacent wild populations to document marine reservoirs of infection and validate maricul-ture management practises.

1.7.3 References

ICES. 2005. Report of the Working Group on Pathology and Diseases of Marine Organisms (WGPDMO), 8–12 March 2005, La Tremblade, France. ICES CM 2002/F:02 112 pp.

ICES. 2008. Report of the Working Group on Pathology and Diseases of Marine Organisms (WGPDMO), 4–8 March 2008, Galway, Ireland. ICES CM 2008/MCC:01 128 pp.

ICES. 2009. Report of the Working Group on Pathology and Diseases of Marine Organisms (WGPDMO), 24–28 February 2009, Riga, Latvia. ICES CM 2009/MCC:01 119 pp.

ICES. 2010. Report of the Working Group on Pathology and Diseases of Marine Organisms (WGPDMO), 23–27 February 2010. Uppsala, Sweden. ICES CM 2010/SSGHIE:02 66 pp.

ICES. 2011. Report of the Working Group on Pathology and Diseases of Marine Organisms (WGPDMO), 1–5 March 2011, Aberdeen, UK. ICES CM 2011/SSGHIE:04 58 pp.

ICES. 2012. Report of the Working Group on Pathology and Diseases of Marine Organisms (WGPDMO), 31 January–04 February 2012. Lisbon. Portugal. ICES CM 2012/SSGHIE:03 74 pp.

ICES. 2013. Report of the Working Group on Pathology and Diseases of Marine Organisms (WGPDMO), 5-9 March 2013 Padova, Italy. ICES CM 2012/SSGHIE:03 30 pp.

ICES. 2014. Report of the Working Group on Pathology and Diseases of Marine Organisms (WGPDMO), 25-28 February 2014 ICES Headquarters, Copenhagen, Denmark. ICES CM 2012/SSGHIE:02 28 pp.

Annex 9: Emerging Issues

ToR c: Identify emerging aquaculture issues and related science advisory

needs for maintaining the sustainability of living marine resources and the protection of the marine environment. The task is to highlight new and important issues that may require additional attention by the WGAQUA and/or another Expert Group as opposed to providing a comprehensive analysis.

During the ASC in Bergen, key science areas for WGAQUA were identified based on a scoping exercise and analysis of a questionnaire sent to all ICES member states by WGEIM and WGMASC. These were grouped into the three categories; 'Economic and ecological efficiency', 'Management tools to ensure sustainability' and 'Interactions with the natural environment and fisheries' (see Table 9.1).

Table 9.1. List of proposed science themes and topics for WGAQUA (from 2012 Aquaculture Discussion Paper).

Economic and ecological efficiency	IMTA
	Off-shore issues
	Spat supply
	Diversification for new species
	Bioremediation
	Goods and services
	Animal welfare and domestication
Management tools to ensure sustainability	Marine Spatial Planning
	thresholds and indicators
	Carrying capacity
	Pest and predator management
	Eco-certification
	Risk assessment and dealing with uncertainty
	EU Framework Directives

Interactions with natural environment and fisheries	Escapees
	Sea lice
	Carrying capacity
	Pest and predator management
	Spat supply
	Climate change
	Goods and services
	Impact on fisheries

During this, the first, work cycle of WGAQUA, a scoping exercise was conducted to further refine the above list of aquaculture issues and to identify issues that could be better addressed by other EGs. Table 9.2 provides a summary of the central topics identified by WGAQUA and Table 9.3 summarizes aquaculture topics best suited to be addressed by other EGs, albiet with requested input from WGAQUA.

Table 9.2. Relevant aquaculture issues sorted by thematic group as defined by EATiP and topics addressed in WGAQUA group discussions.

Thematic groups suggested by EATiP	Central topics defined by WGAQUA
Integration with the Environment	• Benthic impacts • Introduction of new species and transfer of species between countries • Interaction of escapees with natural environment (*genetic*, ecological) • Ecological carrying capacity • Introduction of hard substrate/ structures • Capture based aquaculture • Interaction with wild populations/species
Technology & Systems	• Off shore (exposed) • Land based, RAS • Prevent escapees • Enclosed systems (e.g. sea cages) • IMTA, nutrient trading, upwelling • Juvenile supply • Production practice • Macroalgae production • Pest management (biofouling and predator control)
Product quality, Consumer Safety & Health	• Traceability (*genetic*, farm to fork and fork to farm) • Different feed (organoleptic, fish quality/taste, health value, fish health) • Functional food (omega 3)
Managing the Biological Lifecycle	• Domestication • Improving yield of hatcheries • Juvenile quality • Optimising production cycle
Sustainable Feed Production	• Feed sources (how to use available sources or produce feed for fish – mussels/macroalgae/single cell proteins/invasive species/plant production) • *GMO* (soymeal supply) • Phytoplankton production (feed, biofuel?)
Knowledge Management	• Tools to make scientific and technological knowledge available to managers and industry
Socio-economics, Management & Governance	• Market (development, segmentation, differentiation, branding) • Educated consumer • Training aquaculture people • Monitoring program (indicators and thresholds) • Risk assessment

	• Need for regulations, EU directives, licencing (space, time, environment) EATiP • Standards • Marine spatial planning of aquaculture
Aquatic Animal Health & Welfare	• Pest management (sea lice) • Fish welfare

Table 9.3. Relevant aquaculture issues suited to be addressed largely by other groups within ICES in collaboration with WGAQUA.

Topic	ICES group
Socio-economics (externalities, viability, coastal communities, food security)	WGSEDA
Microplastics	MCWG
Climate change	SGOA, WKSICCME…
Disease, probiotics, vaccine development, medicines	WGPDMO
Marine spatial planning (cumulative effects, zonation ICZM, spatial scale)	WGMPCZM
Harmful algal blooms	WGHABD
Transport (well boat, pest management)	WGITMO, WGBOSV
Statistical and analytical methods for quantifying genetic introgression of farmed escaped salmon in native populations	WGAGFM

WGAQUA was originally tasked to annually review the state of knowledge of the key issues within the topic area of sustainability as well as to identify emerging scientific issued that need to be further developed. The issues identified in Tables 9.1 and 9.2 are extremely broad and it was therefore necessary for WGAQUA to focus on a shortened-list of key issues that matched the expertise that exists within the group. The above scoping exercise led to the selection of three work themes that will form the pillars of future WGAQUA work:

1. Aquaculture Technologies and Ecological Services
    - Off-shore issues
    - Spat supply
    - Diversification for new species
    - Bioremediation
    - Goods and services
    - Animal welfare and domestication
2. Sustainable Aquaculture Management Approaches
    - Marine Spatial Planning
    - Thresholds and indicators
    - Carrying capacity
    - Pest and predator management

- Eco-certification
- Risk assessment and dealing with uncertainty
- Governance

3. Environment and Fisheries Interactions with Aquaculture.
   - Escapees
   - Sea lice
   - Carrying capacity
   - Pest and predator management
   - Spat supply
   - Climate change
   - Goods and services
   - Impact on fisheries

In the future, these or other themes may be organized as subsidiary EGs reporting to WGAQUA who synthesizes their work and presents a common report to SCICOM and ACOM.

During the 2015 meeting, WGAQUA members identified a short list of *emerging* scientific issues, some of which could be addressed in our next work cycle along with the continuation of work on some priority topics. The main issues identified, in no particular order, were:

a. Effectiveness of open-water Integrated Multi-Trophic Aquaculture (IMTA) operations to recycle and extract particulate and dissolved wastes generated by fish culture.
b. Feasibility of closed containment systems as an alternative to open-water net-pen fish culture.
c. Ecosystem interactions and health and welfare issues associated with the use of alternatives to traditional fish feed components (e.g. terrestrial plants and insects, shellfish, ascidians, microbes, seaweed, etc.)
d. Potential role of aquaculture in establishing food security.
e. How to define an acceptable impact level and spatial zone (i.e. what is a "sustainable" aquaculture operation). What are appropriate ecological carrying capacity thresholds? These answers require the development of management frameworks and systems that integrate science and socio-economic considerations.
f. Is ocean acidification presently impacting aquaculture production in the ICES area?

Subsequent discussions on potential new ToRs for the next WGAQUA work cycle identified issues "b" (fate and effects of alternative feeds), "c" (defining acceptable impact thresholds) and "d" (ocean acidification and aquaculture) as topics that require attention by WGAQUA (see Annex 4: WGAQUA terms of reference for next meeting).

Annex 10: Tools for Monitoring Changes in Marine Benthic Habitats

ToR d: Identify and assess approaches for analysing the effects of aquaculture on benthic habitats with a focus on rocky and mixed substrata bottoms. Recommend approaches to assess/monitor these habitats

ToR e: Identify and assess approaches for analysing the interactions between aquaculture and eelgrass and maerl beds. Recommend approaches to assess/monitor these habitats

ToR j: Assess the knowledge base on acceptance of aquaculture in Marine Protected Areas

Evaluating tools for monitoring changes in marine benthic habitats associated with aquaculture

Background:

Aquaculture has been responsible for the continuing growth in global fish production since capture production levelled off in the mid-1990s (FAO, 2012). Aquaculture contributions to total world fish production climbed steadily from 20.9 percent in 1995 to 40.3 percent in 2010. Mariculture operations in ICES member countries produced a total of 2.33 million tonnes of aquaculture seafood products, 3.5 % of the total world aquaculture production. Both fish and bivalve molluscs dominated the total production within ICES countries (2.324 million tonnes), with other mariculture species (aquatic plants and other shellfish) contributing only a small fraction of the total production (6,852 tonnes). Across all ICES member countries, Norway contributed 57% of all production in the ICES region, Spain was the second largest producer (9.1%), with the UK (8.2%), France (6.3%) and the USA (6.5%) also among the top-5 producers in the ICES region (Fig. 1) (FAO, 2012).

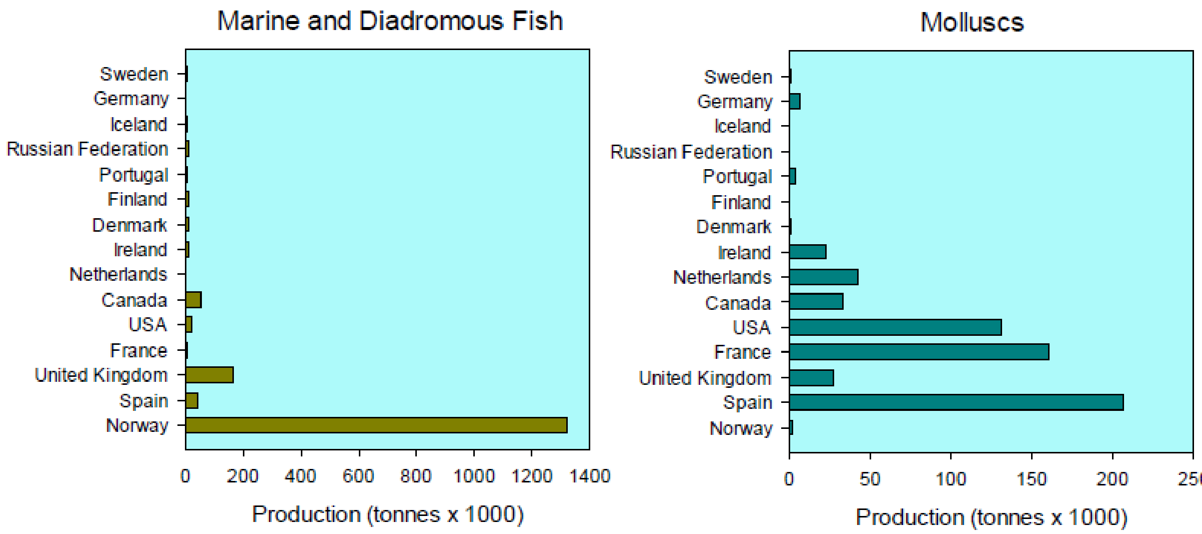

Figure 1. Aquaculture production of marine and brackish water fish and molluscs by ICES member countries in 2012 (Statistics from the on-line FAO database). Countries are listed in order of total production. Note that this analysis neglected to include the Faroe Islands, which produced 72 000 tonnes of Atlantic Salmon in 2012; making it the 7th largest aquaculture producer in the ICES region. (ICES WGAQUA Report 2014).

Within temperate marine ecosystems, the development of mariculture operations has rapidly progressed over the past two decades, spanning a wide range of cultivated marine species that interact directly with benthic ecosystems. Mariculture activities include both extensive and intensive operations, and the degree of environmental interaction is a function of ambient environmental conditions, the husbandry practices of the operations, and the sensitivity of the receiving ecosystem and associated organisms (Holmer *et al.* 2005). Extensive mariculture operations include the cultivation of bivalves, primarily mussels and oysters using suspended and bottom culture techniques, while intensive aquaculture includes the cultivation of diadronomous and marine fish (i.e. salmon, trout, seabream, seabass) in net cages. With an increasing reliance on aquaculture to meet the global demands for seafood, raw materials and renewable energy resources, several new and emerging species (i.e. seaweeds, sea urchins, tunicates) are also being cultivated to meet these market demands and to help with the mitigation of associated environmental impacts from intensive fin-fish cultivation.

With increasing development of mariculture operations, both in terms of the size and number of sites, there is an increasing focus of maintaining environmental sustainability. Such an environmental focus has resulted in a strong interest to identify new locations and the relocation of existing operations to deeper and more exposed localities that may be dominated by different substrate types and organisms. As such, environmental pressure from mariculture activities will and have been shifting from habitats dominated by soft sediment substrates to habitats with heterogeneous mixed and hard bottom substrate types. These substrate types contain different habitats, such as, rocky reefs, macroalgal communities (i.e. Kelp forests and other seaweeds), as well as biogenic features (seagrasses, mearl beds, saltmarshes, carbonate sandy sediments, sponge gardens, cold-water coral reefs, mussel beds etc; Worm and Summer 2000; Bongiorni *et al.* 2003; Hall-Spencer *et al.* 2006; Villanueva *et al.* 2006; Diaz-Almela *et al.* 2008; Duarte *et* *al.* 2008; Sanz-Lazaro *et al.* 2011; Aquado-Gimènez and Ruiz-Fernàndez 2012; Wilding *et al.* 2012). Furthermore, over the past decade there has also been an emerging awareness and identification of sensitive habitats within marine ecosystems. These habitats and the species they support can play important roles in the functioning of the ecosystems within which they are found. With increasing relocation and siting of new farms into habitats that lack scientific investigations there is increasing concern over the impacts of aquaculture activities on these sensitive habitats and species. Huntington *et al.* (2006) identified some of the environment impacts of aquaculture within sensitive habitats. They classified these impacts into eleven main pressure categories (see Table 1). Some of the main types of aquaculture currently practiced within ICES member states and their potential impacts on marine habitats in terms of the pressure categories identified by Huntington *et al.* (2006) are discussed below.

With a rapidly expanding industry, the development and establishment of monitoring methodology and tools for detecting and evaluating environmental impacts of aquaculture to marine ecosystems has been a topic of considerable interest for traditional cultivation locations (i.e., soft sediment habitats). However, the gradual relocation of aquaculture facilities to deeper and/or more dynamic 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 ensure long-term environmental sustainability. The aim of this Term of Reference (ToR) is to 1) compile our existing knowledge of the drivers of ecological impacts from mariculture, 2) review how mariculture activities are monitored and 3) to provide an overview of how what tools could be used in environmental monitoring for non-soft sediment substrates.

Drivers of ecological impacts

Details of the potential biological and physical effects of aquaculture activities on marine habitats, their sources and the mechanism by which the ecological impacts may occur are summarised in Table 1 below (reviewed in Black 2001; McKindsey *et al.* 2007, 2011; NRC 2009; NRC 2010; O'Beirn *et al.* 2012; Cranford *et al.* 2012).

Shellfish culture comprises primarily filter feeding organisms which, for the most part, feed at the lowest trophic level, usually relying primarily on ingestion of phytoplankton. The process is extractive in that it does not rely on the input of feedstuffs in order to produce growth. Suspension feeding bivalves such as oysters and mussels can modify their filtration to account for increasing loads of suspended matter in the water and can increase the production of faeces and pseudofaeces (non-ingested material) which result in the transfer of both organic and inorganic particles to the seafloor. This process is a component of benthic-pelagic coupling, however, the degree of deposition and accumulation of biologically derived material on the seafloor is a function of a number of factors discussed below.

In addition, the placement of structures associated with suspended culture can influence the degree of light penetration to the seabed. This is likely important for certain organisms and habitats e.g. Maërl and seagrasses which need sun light for production. Rafts or lines will, to a degree, limit light penetration to the sea bed and may therefore reduce production of photosynthesising species. However, such effects have not been demonstrated for seagrasses. Specific to intertidal culture practices, there is a risk of physical disturbance can also be caused by compaction of sediment from foot traffic and vehicular traffic. Activities associated with the culture of intertidal shellfish include the travel to and from the culture sites and within the culture sites using tractors and trailers as well as the activities of workers within the site boundaries. Intertidal culture of clam species is typically carried out in the sediment covered with netting to protect the stock from predators. The high density of the culture organisms can lead to exclusion of native biota and the ground preparation and harvest methods (by mechanical means or by hand) can lead to considerable disturbance of biota characterising the habitat. Netting can result in increased accretion of sediments and greater build-up of fine sediments (Spencer *et al.* 1997, 1998).

Sub-tidal on-bottom shellfish culture (i.e. mussels) involves re-laying shellfish on the seabed. There may be increased enrichment due to production of faeces and pseudofaeces in high density cultures. The existing in-faunal community may be changed as a result (Ysebaert *et al.* 2009). Seabed habitat change may also occur as a result of dredging during maintenance and harvesting operations. Uncontained sub-tidal shellfish culture will lead to changes in community structure and function through the addition, at high % cover, of an epi-benthic species (living on the seabed) to an infaunal sedimentary community. The husbandry activities associated with this culture practice (dredging of the seabed) are considered disturbing which can lead to removal and/or destruction of infaunal species, sediment resuspension and potential changes to sediment composition.

Finfish Culture: Finfish culture differs from shellfish culture in that there is an input of feed into the system and as a consequence a net input of organic matter to the system. This material will be found in the system in the form of waste feed (on the seafloor), solid waste (faeces), and waste as a consequence of net-cleaning all of which usually accumulates on the seafloor, as well as dissolved material (predominantly fractions rich in nitrogen). For the most part, the majority of organic material builds up on the seabed generally in and around the footprint of the salmon cages with a 'halo' effect evident in areas where dispersion occurs driven by local hydrographic conditions. This is typically referred to as *near-field* effects.

Wildish *et al.* (2004) and Silvert and Cromey (2001) both summarize the factors (listed below) that govern the level of dispersion of material from the cages to the seafloor. Many of the factors are subsequently incorporated into modelling efforts which are used to predict likely levels of impact. The impact of organic matter on sedimentary seafloor habitat typically evolves after the gradient defined by Pearson-Rosenberg (1978), whereby as the level of organic enrichment increases the communities (macrofaunal species number and abundance) found within the sedimentary habitats will also change. The shift from an oxygenating to reducing environment in the sediment could be such that the effect is mirrored in the water column as well (i.e. reduction in oxygen levels). Antifouling compounds for the net pens are used in fish farming. The most common is copper, and while this compound was meant to be phased out, it has proven difficult to find a substitute. Copper is released into the marine environment (and can accumulate on the seabed) when nets and cages are washed off in the ocean at the aquaculture sites using high pressure washers.

For all culture activities identified above the extent of the impacts are governed by a range of factors primarily:

- Hydrography; low current speeds may result in material being deposited directly beneath the farming structure. If large volumes of water move through the culture area an acceleration of water flow can occur beneath the trestles, bags and nets resulting in a scouring effect or erosion and no accumulation of material.
- Turbidity of water; many bivalve species (oysters and mussels) have plastic response to increasing suspended matter in the water column with a consequent increase in faecal or pseudo-faecal production. Oysters can be cultured in estuarine areas (given their polyhaline tolerance) and as a consequence can be exposed to elevated levels of suspended matter. If currents in the vicinity are generally low, elevated suspended matter can result in increased build-up of material beneath culture structures.
- Density; higher densities of culture organisms will increase the likelihood of accumulation of waste products on the seafloor. In addition, the density of culture structures is also a factor. The closer the proximity of structures, a dampening effect can be realised with resultant accumulations. Close proximity may also result in impact on performance of culture organism (production) due to competitive interactions for food. The density of culture organisms is a function of:
    - Depth of the site (shallower sites have shorter droppers for bivalves and net depth for finfish and hence fewer culture organisms),
    - The husbandry practices. For shellfish, proper maintenance will result in optimum densities on the lines in order to give high growth rates as well as reducing the risk of drop-off of culture animals to the seafloor and sufficient distance among the longlines (or farms) to reduce the risk of cumulative impacts in depositional areas.
- Exposure of sites - the degree to which the aquaculture sites are exposed to prevailing weather conditions will also dictate the level of accumulated organic material in the area. As fronts move through culture areas increased wave action will re-suspend and disperse material away from the trestles (Mallet *et al.* 2006, 2009; Forde *et al.* In press).

Table 1. Drivers of ecological effects of mariculture activities.

Activity	Pressure category	Pressure	Potential effects	Equipment
Suspended shellfish culture methods	Physical	Current alteration	Baffling effect resulting in a slowing of currents and increasing deposition onto seabed changing sedimentary composition. Increased retention time also possible. Erosion may be possible if scouring occurs around structures (droppers or anchor blocks)	Floats, longlines, continuous ropes and droppers and anchor blocks.
	Biological	Organic enrichment	Faecal and pseudofaecal deposition on seabed potentially altering community composition. Drop-off of culture species.	
		Shading	Prevention of light penetration to seabed potentially impacting light sensitive species	
		Fouling	Increased secondary production on structures and culture species. Increased nekton production	
		Seston filtration	Alteration of phytoplankton and zooplankton communities and potential impact on carrying capacity	
		Nutrient exchange	Changes in ammonium and dissolved inorganic nitrogen resulting in increased primary production. Nitrogen (N_2) removal at harvest.	
		Alien species	Introduction of non-native species with culture organism transported into the site, structures provide predator-free habitat for invasive species to occupy.	
Intertidal shellfish Culture	Physical	Current alteration	Structures may alter the current regime and resulting increased deposition of fines or scouring.	Netting, trestles and bags and service equipment
		Surface disturbance	Ancillary activities at sites, e.g. servicing, transport increase the risk of sediment compaction resulting in sediment changes and associated community changes.	
		Shading	Prevention of light penetration to seabed potentially impacting light sensitive species	

Activity	Pressure category	Pressure	Potential effects	Equipment
	Biological	Non-native species introduction	Potential for non-native culture species (*C. gigas*) to reproduce and proliferate in area. Potential for alien species to be included with culture stock (hitch-hikers).	
		Disease risk	In event of epizootic the ability to manage disease in uncontained subtidal oyster populations is compromised.	
		Organic enrichment	Faecal and pseudofaecal deposition on seabed potentially altering community composition	
Subtidal (on-bottom) Shellfish culture	Physical	Surface disturbance	Abrasion at the sediment surface and redistribution of sediment	Dredge
		Shallow disturbance	Sub-surface disturbance to 25mm from dredging operations	
	Biological	Monoculture	Habitat dominated by single species and transformation of infaunal dominated community to epifaunal dominated community.	
		By-catch mortality	Mortality of organisms captured or disturbed during the harvest process, damage to structural fauna of biogenic structures.	
		Non-native species introduction	Potential for alien species to be included with culture stock (hitch-hikers)	
		Disease risk	In event of epizootic the ability to manage disease in uncontained subtidal shellfish populations would likely be compromised. The risk introduction of disease causing organisms by introducing seed originating from the 'wild' in other jurisdictions	
		Nutrient exchange	Increased primary production. N_2 removal at harvest or denitrification at sediment surface.	
Finfish	Biological	Nutrient exchange	Increased primary production. N_2 removal at harvest or denitrification at sediment surface.	Netting, anchors

Activity	Pressure category	Pressure	Potential effects	Equipment
		Organic enrichment	Faecal and waste food on seabed potentially altering community composition	
	Physical	Current alteration	Structures may alter the current regime and resulting increased deposition of fines or alternatively scouring.	
	Chemical	Parasite treatments, antifoulants on nets	In feed treatments falling to seafloor can lead to build-up of chemotheraputents on seafloor. Husbandry practices cleaning of nets leading to build-up of antifoulants, e.g. copper on seafloor	

Habitat Sensitivity:

In addition to the pressures resulting from the culture activities highlighted above, the degree and hence, the likely significance, of the impact is also governed by features of the receiving environment including features such as faunal and community sensitivity. Sensitivity of a species to a given pressure is the product of the intolerance (the susceptibility of the species to damage, or death, from an external factor) of the species to the particular pressure and the time taken for its subsequent recovery (recoverability is the ability to return to a state close to that which existed before the activity or event caused change). Life history and biological traits are important determinants of sensitivity of species to pressures from aquaculture.

In the case of species, communities and habitats, the separate components of sensitivity (intolerance, recoverability) are relevant in relation to the persistence of the pressure:

- For persistent pressures, i.e., activities that occur frequently and throughout the year recovery capacity may be of little relevance except for species/habitats that may have extremely rapid (days/weeks) recovery capacity or whose populations can reproduce and recruit in balance with population damage caused by aquaculture. In all but these cases and if sensitivity is moderate or high then the species/habitats may be negatively affected and will exist in a modified state. Such interactions between aquaculture activity and species/habitat/community might represent persistent disturbance unless appropriate mitigation measures are applied.
- In the case of episodic pressures i.e., activities that are seasonal or discrete in time both the intolerance and recovery components of sensitivity are relevant. If sensitivity is high but recoverability is also high relative to the frequency of application of the pressure then the species/habitat/community will be likely in favourable conservation status for at least a proportion of time.

Certain guidelines will broadly underpin the analysis and conclusions of the species and habitat sensitivity assessment:

- Sensitivity of certain taxonomic groups such as emergent sessile epifauna to physical pressures is expected to be generally high or moderate because of their form and structure (Roberts *et al.* 2010). Also high for those with large bodies and with fragile shells/structures, but low for those with smaller body size. Body size (Bergman and van Santbrink 2000) and fragility are regarded as indicative of a high intolerance to physical abrasion caused by fishing gears (i.e. dredges). However, even species with a high intolerance may not be sensitive to the disturbance if their recovery is rapid once the pressure has ceased.
- Sensitivity of certain taxonomic groups to increased sedimentation is expected to be low for species which live within the sediment, deposit and suspension feeders; and high for those sensitive to clogging of respiratory or feeding apparatus by silt or fine material.

Recoverability of species depends on biological traits (Tillin *et al.* 2006) such as reproductive capacity, recruitment rates and generation times. Species with high reproductive capacity, short generation times, high mobility or dispersal capacity may maintain their populations even when faced with persistent pressures; but such environments may become dominated by these (r-selected) species. Slow recovery is correlated with slow growth rates, low fecundity, low and/or irregular recruitment, limited dispersal capacity and long generation times. Recoverability, as listed by MarLIN, assumes that the impacting factor has been removed or stopped and the habitat returned to a state capable of supporting the species or community in question. The recovery process can be complex and therefore the recovery of one species does not necessarily signify that the associated biomass and functioning of the full ecosystem has recovered (Hall *et al.* 2008).

Current environmental monitoring of benthic environmental changes associated with finfish mariculture.

Legislative and/or regulatory requirements for monitoring benthic environmental changes are typically required as a means to evaluate the extent or degree of environmental impacts of mariculture activities, although the standardized monitoring protocols are limited to fin-fish mariculture located over soft or mixed sediment ocean substrates. Table x summaries required benthic environmental monitoring in four salmon producing ICES countries (Norway, Canada, Ireland and Scotland). In each country, there are operational benthic environmental monitoring requirements for all farms, as well as additional monitoring, which may be required. The countries and monitoring requirements were chosen to provide a view to some of the monitoring differences used within ICES member countries, and to highlight similarities in approaches. In all countries examined, near farm (or near field) monitoring is mandatory. However, only Norway implements far-field monitoring, should the environmental thresholds for near field benthic environmental indicators be surpassed, or if otherwise required by the regulatory authority (Table 2).

In addition to soft sediment sampling, there are some requirements for benthic change monitoring where a sediment sample cannot be obtained. In these cases, visual survey monitoring is required, using drop-cameras, ROVs or diver visual surveys at peak biomass (i.e., Canada and Scotland). In Canada the indicators used are the percent cover of *Beggiatoa*-like species and/or OPC (opportunistic polychaete mat communities), and substrate analysis to indicate habitat type, location of type of farm litter and debris, farm waste and faecal pellets, and presence and relative abundance of sensitive, opportunistic and resource/conservation taxa. There is only a threshold for the coverage of Beggiatoa-like species and/or OPC, in that they must not exceed 10% in four or more of the segments in the zone of compliance; and must not exceed 10% in any two contiguous segments in the post-compliance zone (124 – 140 m from the containment structure array edge) if the coverage exceeds 10% in both of the last two segments of the zone of compliance. In Scotland a site specific Allowable Zone of Effect (AZE) (within which some exceedance of Environmental Quality Standards (EQS) or environmental damage is permitted), is determined using the AutoDEPOMOD modelling package, at each new site (SEPA 2006). Thresholds, in the form of Action Levels, have been set for *Beggiatoa* and the presence of Feed Pellets. *Beggiatoa* mats must not be observed outside the AZE (SEPA 2006). Accumulations of feed pellets must not be observed within the AZE and no pellets should be observed outside the AZE (SEPA 2006). However it should be noted that the benthic standards for monitoring at fish farms in Scotland are currently under review and therefore the information contained above may not be the most up to date (SEPA pers com.). The new thresholds and indicators of impact were not available at the time of writing. In Norway, alternative monitoring may be required if the standard benthic monitoring cannot be used because of deep water or hard bottom substrates. Unfortunately here are no suitable methods for hard bottom investigation to day, and there is also a limitation in existing Norwegian legislative processes for this type of habitat.

Table 2. Analytical methodology and monitoring thresholds for fin-fish mariculture activities across 4 major Atlantic Salmon producing ICES member states.

Analytical Measurements	Norway - Standard Monitoring	Norway - Intermediate and Regional Monitoring	Canada - Standard Monitoring	Canada - Additional Monitoring	Ireland - Standard Monitoring	Ireland - Additional Monitoring (>1000T and <5cm/sec)	Scotland - Standard monitoring (<1,000 tonnes)	Scotland - Extended monitoring (≥1,000 tonnes or environmentally sensitive area)	Scotland - Visual monitoring (<500 tonnes or where soft-sediment sampling impractical.
Faunal Assessment	Present/Absent	Quantitative and qualitative benthic community	Can be required, regionally dependent	Can be required, regionally dependent	not required	Quantitative macro-invertebrate (uni-variate and multi-variate indices)	species/abundance matrix, diversity indices, ITI, evenness indices	species/abundance matrix, diversity indices, ITI, evenness indices	Video (diver/ROV or drop down/towed video) and stills.
Chemical	pH, Eh	TOC, P, Zn, Cu, Oxygen, Salinity, Temp	free sulfides, Eh	free sulfides, Eh	TOC (LOI); Redox	TOC (LOI); Redox	Eh, Organic carbon,	Eh, Organic carbon, In-feed treatment residues survey	
Sensory	Gas bubbles, colour, off-gasing, etc.	Sediment grain size	Can be required, regionally dependent	Can be required, regionally dependent	visual assessment (presence of waste material - feed, fecal pellets). Gas bubbles, bacterial mats	visual assessment (presence of waste material - feed, fecal pellets). Gas bubbles, bacterial mats	colour, physical consistency, texture, presence pf feed pellets and/ Beggiatoa noted. PSA	colour, physical consistency, texture, presence pf feed pellets and/ Beggiatoa noted. Depth of organic waste overlying "real" sediment noted. PSA	

Threshold	Combination of all three assessments will determine if additional sampling may be required		Mean concentration of free sulfides <3000 uM at cage edge OR (B) Mean concentration of free sulfides at 30m from cage edge < 1300 uM and mean concentration of free sulfides at 125m from cage edge<700 uM	If continue to exceed threshold in standard monitoring, must not restock until mean concentration of free sulfides are less than the threshold	Twice reference site levels for LOI and Redox; bacterial mats >50% coverage	Twice reference site levels for LOI and Redox; bacterial mats >50% coverage	The benthic standards for monitoring at fish farms in Scotland are currently under review (SEPA pers com.). The new thresholds and indicators of impact were not publically available at the time of writing however further information regarding those currently used can be obtained from SEPA.

Sources: Anon 2007, Norwegian Standard NS9410 (NS 9410:2007) as established in the Aquaculture Operation Regulations;

Canada; Pacific Aquaculture Regulations, etc.

Ireland:

Scotland: *SEPA 2008. Regulation and monitoring of marine cage fish farming in Scotland - a procedures manual. Annex F: Seabed Monitoring and Assessment http://www.sepa.org.uk/regulations/water/aquaculture/fish-farm-manual/

SEPA, 2006. Regulation and monitoring of marine cage fish farming in Scotland – a procedures manual. Annex A Standards. March 2006

Lessons to learn from Soft sediments to apply to new habitats

While standard approaches for using different types of environmental monitoring techniques are available (Table 3), knowledge on the transferability of existing tools that quantify environmental change from soft sediment ecosystems to other substrate/habitat types is often lacking. Furthermore, establishment of appropriate thresholds and indicators for assessing benthic changes associated with aquaculture located over different substrate types are not always available. This dearth of information is driven by a lack of rigorous scientific investigations in non-soft sediment ecosystems. Therefore, there is an urgent need to develop new knowledge on how non-soft sediment ecosystems respond to organic and inorganic nutrient loading. This also includes establishing indicators, thresholds and monitoring practices to enable environmental managers to assess the impact of mariculture on habitat types that do not conform to soft sediment substrates.

Table 3: Identification of sampling techniques across different substrate types

Monitoring Technique	Soft	Mixed	Hard	Eelgrass	Marlbed
Physical Samples					
Grab sample for chemical analysis And fauna identification	X	?		X	
Diver cores	X	?		X	
Visual Surveys					
Drop camera	X	X	X	X	X
ROV	X	X	X	X	X
Video quadrats	X	X	X	X	X

Addressing monitoring needs for non-soft sediment habitats and/or sensitive habitats should be approached through the development of new and the use of existing indicators and/or tools to measure changes in the structure and function of benthic ecosystems. Such tools and/or indicators should consider both local and regional scale effects and where possible should be linked to existing or new international standards. The use and/or selection of bio-indicators should be established to ensure that changes in benthic environmental condition can be established and whether the change in environmental condition can be linked directly back to the source of perturbation. It is highly likely that a number of tools will need to be established for this purpose indicators and/or tools that require consideration are as follows:

Surveying tools:

1. Visual surveys: Visual surveying techniques have been established for mapping changes in seabed communities using a variety of systems, including diver assisted surveys, towed video systems, drop cameras and remotely operated vehicles. Standards for seabed surveying techniques have been established (Anon 2009) and it is recommended that the methodology outlined in this standard should be followed when establishing a monitoring program centered on the use of these tools (ref to standard). Like grab sampling, visual surveys

will be important to establish visual evidence of substrate condition, the presence/absence of waste components from mariculture and a shift in the composition and abundance of key fauna/flora communities.

2. Autonomous Underwater Vehicles: The autonomous underwater vehicles (AUVs) can produce bathymetric, sidescan, subbottom, and magnetic maps of the seafloor and are capable of taking digital bottom photographs in a variety of habitat types. Additional sensors for measuring CTD, dissolved oxygen, chlorophyll, pH, ORP (oxidation reduction potential) and turbidity, as well as an acoustic Doppler current profiler (ADCP) and Doppler velocity log can be added to AUVs which allow continuous water quality measurements in addition to visual mapping of the seabed. This techniques could result in rapid and detailed data collection, at farming locations, leading to a detailed understanding of the impact of the mariculture activity. Such a detailed mapping study has been undertaken at a mussel farm in Lorbé (Zuñiga *et al.* 2014), Galicia (Spain).

Bio-indicator tools:

1. Meta-barcoding tools: Protist metabarcoding tools are being established using next-generation sequencing (NGS) of environmental DNA and RNA extracted from sediment samples. Work by Pawlowski *et al.* (2014) focused on analysing the response of benthic foraminiferal communities to the variation of environmental gradients associated with salmon farms in Scotland. Their study revealed high variations between foraminiferal communities collected in the vicinity of fish farms and at distant locations. They found evidence for species richness decrease in impacted sites, especially visible in the RNA data. They also detected some candidate bio-indicator foraminiferal species. The bonus of these barcoding tools is that the analysis reduced the time and costs associated with, taxonomic sorting and morphology-based identification of the macrobenthos, a huge benefit for environmental managers. In addition, such tools are not restricted to fauna in soft sediment substate types and have the potential to be applied across different substrate types including mixed and hard bottom substrate types, provided samples can be collected.

2. Biotic indices / Sensitive species indices: It has been established that biotic indices should be specifically designed for concrete activities, and further regionally validated, due to the environmental plasticity of marine invertebrates (Aguado-Giménez *et al.* 2015). A number of biotic indices have shown promise with organic enrichment; see Keeley *et al.* (2012) for a range of different indices and their applicability to organic enrichment from aquaculture. It is stressed here that these indices should be used as a guide and if relevant indices or EQS (environmental quality standards) have been established for the region where the mariculture activity is ongoing then these should be utilized.

3. Biological trait analysis: this approach identifies a number of ecological and life history characteristics of marine (invertebrate) organisms that might be

reflective of pressures on the system. Some characteristics that might be incorporated into BTA are; Individual size, colony size, adult longevity, reproductive method/strategy, mobility, feeding type, body form, habitat preference, moitgratory behaviour. Bremner *et al.* (2006) identified that the "selection of biological traits for inclusion in BTA will be based on a trade-off between their efficacy for describing variability in ecological functioning and the time and effort required to gather information on the biological characteristics of the taxa studied".

4. Eddy correlation: The Eddy Correlation is a new technique for quantifying benthic oxygen fluxes (Berg and Huettel 2008; Berg *et al.* 2009; Lorrai *et al.* 2010) and has the potential to measure other benthic fluxes (McGinnis *et al.* 2011). The benefits of this tool is that it is not restricted to one type of ecosystem and has the potential to be applied in environments where traditional enclosure methods are difficult to use Rheuban and Berg (2013), including highly permeable sediments, seagrass meadows (Hume *et al.* 2011; Rheuban *et al.* 2014), hard rocky substrates, coral and oyster reefs (Long *et al.* 2013; Reidenbach *et al.* 2013). The method would also allow for the integration of benthic oxygen demand over an area of several square meters (Lorke *et al.* 2013), considers both the mixing of sediments by organisms living in it and the hydrodynamics of the water above the rough sea floor (McGinnis *et al.* 2014).

Chemical Tracing tools

1. Fatty acids and stable isotopes: The use of chemical tracers such as fatty acids and stable isotopes are important tools to determine the distribution of organic fish farm waste into sediments (Samuelsen *et al.* 1988, Johnsen *et al.* 1993, Henderson *et al.* 1997), zooplankton (Fernandez-Jover *et al.* 2009), epifauna (Olsen *et al.* 2012) and fish (Skog *et al.* 2003, Fernandez-Jover *et al.* 2011). This tool can be used as a chemical indicator to identify the source of organic enrichment, especially important when identifying spatial scale effects and when the environment proposed for mariculture is a multi-user area. These tools can also be used to assess a shift in trophic niche of species and the contribution of basal resources to food webs.
2. Trace elements: Trace elements/minerals are incorporated from the surrounding water into the tissues and calcified structure of an organism in proportion to their concentration in the water, as well as from the diet, although higher regulation of elements is found for dietary incorporation (Reinfelder *et al.* 1998). Fish feeds are supplemented with a range of essential nutrients (e.g. Mn, Fe, Co, CU, Zn; Ni, Mo and Cr) as well as non-essential and/or undesirable nutrients (Cd, As and Hg) (Alasalvar *et al.* 2002, Sissener *et al.* 2013). Trace elements can accumulate form uneaten feed and feces in the sediments below fish cages (Sutherland *et al.* 2007, Mckinnon *et al.* 2011) and become available to benthic filter and detritus feeders as an alternative food source. How these trace minerals from fish farm wastes are incorporated into benthic organisms is not well investigated.

Recommendations/considerations:

This ToR is seen as an important area of advice that requires further refinement and development within a new cycle in order to direct scientific recommendations to improve our ability to establish environmental monitoring programs using appropriate tools to assess the impacts of mariculture in non-traditional ecosystems. State-of-the-art sampling methodologies and tools require further identification, scientific refinement, and an evaluation of practicality and cost-benefit for implementation into national surveying protocols. These tools/methodologies need to be established for the different habitats types, which should be adopted into an international standard that could be utilised as a platform by ICES member countries and other countries globally to establishing monitor programs in substrate types not reflective of soft sediments. However, this would require each country to establish relevant indicators/thresholds based on the ecosystem present and ambient conditions. Furthermore, as existing monitoring programmes are typically designed to identify small-scale (Farm) effects, it is also recommended that if new monitoring protocols are established, the issue of broader effects resulting from cumulative impacts (pressures deriving from the multiple events of the one culture activity) or in-combination effects (similar pressures deriving from differing culture activities) should be considered. This has been a recurrent issue for decades (Levin 1992). Where possible, it is highly recommended that fundamental baseline surveys should carried out before the mariculture activity is implemented (i.e. BACI surveys - Underwood 1989). This would give a true picture to ecological response which is often masked when surveying after the fact.

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Annex 11: Aquaculture Pest Management

ToR f: Analyse and assess the environmental effects of biofouling pest management in aquaculture with an emphasis on i) chemical release, ii) benthic organic enrichment, iii) waste management, and iv) propagule pressure. Ultimately, a risk assessment framework will be developed with respect to treatments for bivalve aquaculture pests within a greater pest management framework.

ToR g: Analyse and assess the environmental effects of sea lice pest management in aquaculture with an emphasis on i) therapeutant release, ii) waste management, and iii) propagule pressure.

ToR k: Characterize risks, real and perceived, and potential ecological benefits associated with introducing foreign strains and species of finfish and shellfish and other invertebrates for aquaculture purposes

Environmental effects of sea lice pest management in aquaculture (ToR g)

Executive Summary

In order to develop an evidence based protocol for the evaluation of the environmental effects of sea lice pest management WGAQUA has assessed the current state of the art in Risk Analysis and the state of knowledge in respect of the relevant scientific data. This has involved:

i) reviewing the state of the art as described in national scientific reports ii) reviewing the recent (2010 –present) peer reviewed scientific literature of relevance iii) assessing the current state of knowledge in respect of: use of therapeutants, modes of action, administration methods, persistence in the environment, toxicity, sensitivity of non-target species and near and far field effects.

Treatments fall into two broad categories, those which are administered to the fish in their feed and topical treatments. The mode of treatment has implications for the pathways by which therapeutant residues are dispersed in the environment. Topical treatments are administered by bathing the fish in specified concentrations of the therapeutant. Bath treatments can be conducted in one of three ways: tarping or skirting of the salmon net-pens, or the use of well-boats. Tarpaulin and skirt bath treatments involve decreasing the volume of water in a salmon net-pen by either completely enclosing the net-pen in an impervious tarpaulin (tarping), or by surrounding the net-pen with a series of impervious tarps to a depth below that of the bottom of the raised net without enclosing the bottom of the net-pen (skirting). The prescribed amount of therapeutant to achieve treatment concentration is then added to the net-pen for the recommended time period, at which point the skirt or tarp is removed and the treatment water is released. Well-boat treatments are conducted by pumping cultured salmon into treatment chambers, or wells, in specially designed boats. These boats are fully equipped with fish pumps, water circulation pumps and oxygen equipment (Jackson 2011). The therapeutant is then added to the well for the prescribed time. Following treatment the treatment water is discharged from the well into the surrounding water, while the well is simultane-

ously flushed with fresh seawater. Following flushing, the fish are then pumped back into the net-pen.

Being able to accurately assess the likely exposure of sensitive organisms following the use of an anti-sea lice therapeutant is complex, as it requires a detailed knowledge of hydrography, bathymetry, and distribution of sensitive organisms and their life-stage at the time of treatment. Recent studies in Canada have integrated estimates of therapeutant transport and dispersal using an oceanographic model and toxicity studies to estimate environmentally relevant concentrations that non-target organisms are likely to experience following therapeutant treatments in marine finfish aquaculture sites (Page *et al.*, 2015, Burridge and Van Geest, 2014, Page and Burridge, 2014).

In a Canadian field study, estimating the zone of impact following therapeutant treatment was achieved using fluorescein dye releases within tarped net-pens during pesticide treatment and in well-boat applications, and the field study results used to validate the southwestern New Brunswick FVCOM (Finite Volume Coastal Oceanography Model) (Chen *et al.*, 2003) implementation to provide estimates of impact zones following therapeutant treatments. While there is reasonable model correspondence to the field study results, estimates for application in cases where hydrographic models are not available was also examined, using the current speed and the Okubo (1971, 1974) transport and dispersal model to estimate the zone of influence from the discharge site. Discharge following well-boat application follows jet dynamic steady-state theory.

While the study site was in the Bay of Fundy, New Brunswick, the general approach and information should be applicable in other areas. However, local oceanographic and environmental data is key to improving estimates, particularly related to local hydrography, bathymetry, current local, and stratification, in addition to differences in treatment procedures, will influence the rate and depth of mixing of pesticides post-treatment, and therefore the concentrations and zone of influence.

In Norwegian studies questions have been directed towards effects on important commercial non-target organisms such as; deepwater prawn (*Pandalus borealis*), Norwegian lobster (*Nephrops norvegicus*), lobster (*Homarus gammarus*) and crabs (*Cancer pagurus*) and possible effects on plankton organisms such as *Calanus* sp. These have found residues of diflubenzuron and teflubenzuron in samples of sediments, water and organic suspended particles up to 1000 m from treatment sites. The surveys also revealed residues in various benthic crustaceans caught around the treatment site. Generally, concentrations were small, but in some individuals higher levels were found which may indicate direct consumption of medicated pellets. Based on available knowledge it is difficult to comment on what implications such residues may have for crustaceans resident near farms which use flubenzerons.

The aquaculture industry and its regulators must make decisions which could potentially have major consequences based on incomplete knowledge and with varying degrees of uncertainty. This can only be achieved in a structured way by the use of a formalized risk analysis approach. Use of risk analysis in aquaculture development and management is relatively new. Nevertheless, several protocols exist for estimating environmental risks arising from aquaculture. NOAA developed guidelines for ecological risk assessment of marine fish aquaculture in 2005. This work was further developed by FAO who presented broader guidelines for understanding and applying risk analysis in aquaculture in

2008. The same year GESAMP provided guidelines on environmental risk assessment and communication in coastal aquaculture. Fisheries and Oceans Canada has developed and is implementing an aquaculture science environmental risk assessment framework. Risk analysis is a decision support tool which focuses management efforts on mitigating potential environmental effects. Phillips & Subasinghe (2008) outlined some unifying principles underlying all risk assessments. These are set out below.

1) Problem formulation – to formulate the problem being addressed, and the scope of the risk analysis.
2) Hazard identification – to determine the nature of potential hazards (threat or stressor).
3) Release assessment – to determine the likelihood of a release associated with the hazard.
4) Exposure assessment – to determine the magnitude and extent the physical effects of an undesirable event (identified in the hazard identification and release assessment stages).
5) Consequence assessment – attempts to quantify the possible damage caused by the exposure to the hazard.
6) Risk estimation – consists of integrating the estimation of the probability of release and exposure events with the results of the consequence assessment to produce an estimate of the overall risk or probability of the event occurring.

An integral component of Risk Analysis is risk communication. This is necessary to ensure that the process of risk Assessment is informed by both public and expert concerns but not driven by risk perception rather than evidence based assessment. A key feature of successful risk communication is transparency and availability of information.

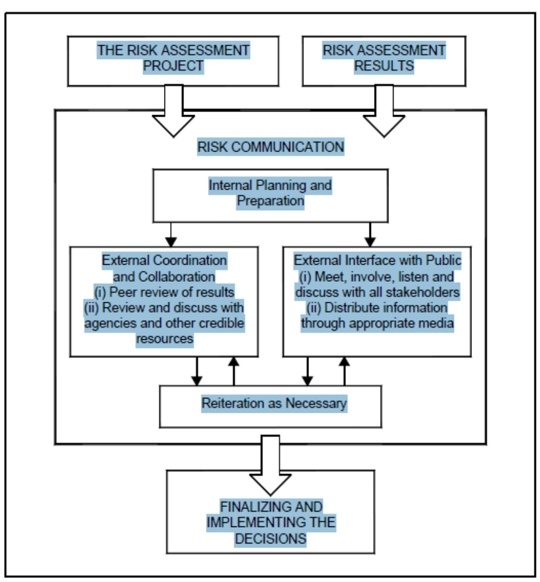

Figure 1. Risk Communication.

(after Nash *et al.* 2005)

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Annex 12: Ecosystem Interactions with Aquaculture

ToR h: Assess and analyse issues relating to the attraction and repulsion of wild populations by fish and shellfish farms and of the impact of this on these populations and the individuals.

ToR i: Analyse and assess the potential ecosystem services and impacts of aquaculture, including extractive aquaculture approaches for environmental impact biomitigation

Attraction and repulsion of wild populations by finfish and shellfish farms

Interaction between fish farms and wild populations

Aspects not covered here: Cultured fish may act as a vector for transferring pathogens to wild fish (Madhun *et al.* 2014) and among farms (Uglem *et al.* 2009) + genetic aspects

Fish farms may influence wild fish populations in different ways. It is known that fish farms can attract wild fish (e.g., Dempster *et al.* 2010, Holmer 2010), marine mammals (Bonizzoni *et al.* 2014), and birds (Buschmann *et al.* 2009). In large part, this occurs through the attraction of animals due to the addition of food (aquafeeds) to the environment and through the addition of physical structure. The former will attract animals by providing them a direct trophic supplement. The latter will create conditions that are attractive to the animals indirectly because the addition of structure provides habitat for organism that, in turn, may attract other species. Husbandry activities may also attract fishes and other wild populations. At the same time, husbandry operations and the addition of feed and structure may repel some species through various mechanisms. If wild fish eat faeces or waste food from a farm, the quality of the wild fish flesh may be altered (e.g. Vita *et al.* 2004, Otterå *et al.* 2009). In the case of therapeutic food treatments, residues also may be found in wild fish living near the farms (e.g.Burridge *et al.* 2010a). Studies also indicate that fish farms may influence the reproduction of wild fish (e.g. Bjørn *et al.* 2009). Here, we address attractive and repulsive effects of finfish cage culture on wild populations, with an emphasis on fisheries-related species, particularly fish. We also discuss various consequences of this on the species that are most affected by finfish cage aquaculture, a summary of which is provided in Figures 1 and 2.

Status of knowledge on attraction of wild fish to fish farms

There is a vast literature showing that wild fish are attracted to finfish farms throughout the world. For example, Carss (1990) found increased numbers of saithe (*Pollachius virens*) around rainbow trout (*Oncorhynchus mykiss*) farms in Scottish lochs. In a comprehensive study of 9 fish farms on the southeast coast of Spain, Dempster *et al.* (2002) found consistently greater abundance, biomass, and species richness of fish communities in the areas directly adjacent to farm sites than in control areas. Likewise, Dempster *et al.* (2009) compared the abundance of wild fish at nine salmon cage sites to paired reference sites in Norway and found wild fish abundance to be 1 to 3 orders of magnitude greater at farm sites. In a subsequent study, Dempster *et al.* (2010) studied the species-specific patterns of aggregation of wild fish around four full-scale coastal salmon (*Salmo salar*) farms in Norway. They found that the total abundance of wild fish was 20 times greater directly adjacent to the farm than at a 200-m from them. The dominant wild fish species found near the salmon farms was the saithe, which they suggested was probably consuming waste feed while schooling near farms. Similar patterns were not found for other species studied. The distribution of both Atlantic cod *Gadus morhua* and poor cod *Trisopterus minutus* varied among farms, with either highest abundances near the farm or a more even distribution of abundance across the distances sampled. No specific pattern of aggregation was evident for the bottom-dwelling haddock (*Melanogrammus aeglefinus*). In a review of the importance of coastal fish farms as fish aggregation devices (FADs), Sanchez-Jerez *et al.* (2011) reported that ca. 160 species of fish have been reported in close proximity to fish farm, although there is only strong evidence that there is a causal relationship for 20 species.

The influence of fish farms may occur at several spatial scales. Vertically, the distribution of attracted fish may vary considerably among farm sites. For example, in a study of 5 farms from the Mediterranean coast of Spain and the Canary Islands, (Dempster *et al.* 2005) found that the abundance and biomass of wild fish were consistently greatest in the depth strata adjacent to cages at the Mediterranean sites but, depending on the farm, were greatest at either the bottom or near the surface at Canary Islands farms. In Norway, fish abundance was consistently greatest at the surface and depths adjacent to salmon farms (Dempster *et al.* 2009). However, the effect in Norway was also species-specific, such that there was a greater richness of fish closer to the bottom and the some species were also most abundant closer to the bottom. In Indonesia, Sudirman *et al.* (2009) reports that attracted fish were most abundant in the depth strata adjacent to sea cages for groupers (*Epinephelus fuscoguttatus* and *Cromileptes altivelis*) and rabbitfish (*Siganus* spp.). Bacher *et al.* (2012) reviewed studies on the influence of fish farms and bottom types on the spatial distribution of fishes and suggest that effects are a function of both farm and bottom type.

As pointed out by Bacher *et al.* (2012), the attractive effect of fish farms may also vary over various horizontal spatial scales. Their study found that the attractiveness of the cage sites differed between locations directly under cages from those at the edge of cage arrays, relative to locations 200m from cages, showing that the attraction effect was largely limited to locations within cage arrays. Dempster *et al.* (2010) evaluated the distribution of fish along transects (0, 25, 50, 100 and 200m) leading from 4 salmon farms. While the spatial distribution of saithe abundance suggests that this species is tightly aggregated around farm sites, patterns for other species were less dramatic (e.g. Atlantic cod) or not evident (e.g. poor cod and haddock). At a larger spatial scale, work done at a series of 3 fish farms in the Aegean Sea Machias *et al.* (2005) found that the abundance of wild fish may be increased even at a considerable distance from the farms (2-3 miles) relative to control sites at > 20 miles distant. Likewise, Arechavala-Lopez *et al.* (2011) showed that bogue *Boops boops* that had aggregated (fed) around fish farms comprised a significant part of the catch by the artisanal Spanish Mediterranean fishery, which operates several kilometers from the fish farms, but did not contribute to the trawl fishery of this species which operates further from the farms. Work by Arechavala-Lopez *et al.* (2010), who used hydroacoustic tagging methods, shows that aggregations of grey mullet (*Liza aurata* and *Chelon labrosus*) around finfish farms may also contribute to commercial fisheries some kilometers from the farm sites. At a slightly larger scale, Goodbrand *et al.* (2013) used hydroacoustic methods to evaluate how sea cage aquaculture affects distribution of wild fish at bay-wide scales. They concluded that a point-source, predictable resource patch, such as a salmon cage farm, within a naturally stochastic environment can enhance biological activity across large spatial scales, increasing the abundance of fish in bays with salmon culture relative to bays without salmon culture. Also using hydroacoustic methods, Giannoulaki *et al.* (2005) showed that fish farms may alter the spatial structure of fish populations over 34 to 82 km^2.

The distribution of fish associated with finfish netpens also varies over a variety of temporal scales. A number of studies have shown that the aggregative effect of fish farms varies over seasons and may only be present at certain times of the year (Valle *et al.* 2007, Fernandez-Jover *et al.* 2008, Dempster *et al.* 2009, Šegvić Bubić *et al.* 2011, Bacher *et al.* 2012, Özgül & Angel 2013). Using traditional tagging methods, (Bjordal & Skar 1992) found increased numbers of saithe to stay for extended periods (months) around a fish farm in Norway. Subsequent work using hydroacoustic telemetry in the same area showed that saithe at the farm either spent most of their time at the farm or else they spent most time elsewhere but visited cages daily (Bjordal & Johnstone 1993). As suggested by the previous study, fish density around farms may also vary throughout the day, as was also shown by Sudirman *et al.* (2009), who suggested this corresponded to feeding time for the farmed fish. Other work has shown that feeding operations-related spatial distribution of fish are species-specific such that some species aggregate around feeding times but that other species do not (Uglem *et al.* 2009, Arechavala-Lopez *et al.* 2010, Bacher *et al.* 2013). A recent study by Bacher *et al.* (2015) around a gilt-head bream *Sparus aurata* farm showed that aggregations were generally increased at feeding times but that the effect was a function of position in the water column, and thus species community, and substrate type.

Mechanisms of attraction of wild fish to fish farms

There are two main ways by which fish farms attract aggregations of fishes: a trophic link (i.e. a heightened availability of food) and fish farms acting as FADs or artificial reefs. In a recent review of the impacts of Norwegian salmon farms on the fish that are attracted to them, Uglem *et al.* (2014) suggest that **waste feed** is the major cause of the attraction of wild fishes to fish cage sites and lists 17 species that have been shown to feed on it at a variety of fish farms. This is somewhat intuitive and is evident by the large number of studies that have found waste feed in the stomachs of wild-caught fish around net pen sites (e.g. Carss 1990, Fernandez-Jover *et al.* 2007, Fernandez-Jover *et al.* 2008, Dempster *et al.* 2010, Fernandez-Jover *et al.* 2011b). Other species may also be attracted by the presence of fish within the cages or else by the aggregated fishes around them (Arechavala-Lopez *et al.* 2014). Attraction due to feeding opportunities due to waste feed and fish aggregations may occur simultaneously and may be a function of the source/quality of waste (ie, composition of aquafeed depend of the species being farmed) and ecology of the wild fishes (species , size, trophic level and feeding strategy) involved (Bayle-Sempere, 2013). For example, Bagdonas *et al.* (2012) studied wild saithe (*Pollachius virens*) and cod (*Gadus morhua*) in the vicinity of salmon farms. Video observations indicated that large numbers of wild fish, in particular saithe, aggregated in close proximity to the cages. The study suggests that dense aggregations of saithe and small cod beneath fish cages were associated with the supply of waste feed whereas larger cod were attracted by the saithe as prey. Similar results were found by Bagdonas *et al.* (2012). Likewise, Arechavala-Lopez *et al.* (2013, 2015) have observed that large predatory fish (tuna and swordfish) to aggregate around Mediterranean fish farms and Papastamatiou *et al.* (2010) have used hydroacoustic tags to document site fidelity and aggregations of sharks around fish farms in Hawaii, underlining the importance of fish farms in aggregating these top predators.

Many studies (see reviews in Rountree 1989, Nelson 2003, Dagorn *et al.* 2013) have found that physical structures in the water column tend to aggregate fishes around them – so called fish attraction/aggregation devices (**FADs**). A large number of studies have shown the importance of fish cage aquaculture structures as FADs (Boyra *et al.* 2004, see reviews in Johannes 2006, but also Tuya *et al.* 2006, Valle *et al.* 2007, Fernandez-Jover *et al.* 2008, Dempster *et al.* 2009, Oakes & Pondella 2009, Sudirman *et al.* 2009, Dempster *et al.* 2010, Sanchez-Jerez *et al.* 2011). Beveridge (1984) lists a number of features that explain how fish cage aquaculture sites act as FADs; see Table 1. Likewise, Sanchez-Jerez *et al.* (2011) discuss how fish farms may act as **artificial reefs** by the presence of additional food, increased feeding efficiency, and the presence of shelter to reduce predation and enhance recruitment. They further suggest that fish farms may be of even greater quality than traditional artificial reefs because of the great quantity of high quality feed that is added to the local environment around cage sites and that may be used by planktivorous fish and stimulate the growth of fouling communities. Indeed, many studies have shown that such fouling communities receive a nutritional boost from the added fish feed (Lojen *et al.* 2005, Callier *et al.* 2013). Likewise, the associated fouling and related communities, including amphipods, small fish, gastropods, etc., may also provide additional trophic resources to aggregated fishes which may then be transferred to higher trophic levels (Dolenec *et al.* 2007, Fernandez-Gonzalez *et al.* 2014).

Much work has shown that netting used in fish cage aquaculture structures is a suitable substrate for the development of rich and abundant fouling communities (see review in Braithwaite & McEvoy 2004). For example, Hargrave (2003) suggests that the biomass of macroalgal communities on salmon net cages in eastern Canada may amount to > 1 kg m^{-2}. An experimental study on the seasonal (monthly) succession on netting material at an offshore cage site in Maine, Greene and Grizzle (2007) showed that the biomass of fouling organisms may reach up to 30 kg m^{-2}, most of which was mussels with other taxa being less abundant seasonally. In Australia, Cronin *et al.* (1999) found that biofouling on tuna farms added an additional 2.2 kg m^{-2} net or a total fouling community of 6.5 tonnes, and Hodson *et al.* (2000) found biofouling of 8.5 kg m^{-2} (mostly ascidians and the green macroalga, *Ulva rigida*) on salmon farm nets. Zongguo *et al.* (1999) examined the fouling communities associated with 5 fish farms in Hong Kong and found between 33 and 55 fouling species per site with a biomass between ca. 4.9 and 11.0 kg m^{-2}. Fouling levels differed between sites and mesh sizes (intermediate mesh sizes of 4 and 6 mm were most heavily fouled) and reached up to ca. 1.4 kg m^{-2} after only 21 days in the water. Madin *et al.* (2010) measured the fouling of mesh panels in a fish cage culture site in Malaysia and found the biomass of sessile and mobile organisms to reach ca. 2.2 and 0.27 kg m^{-2}, respectively, after only 8 weeks immersion. Many other examples are given in Braithwaite and McEvoy (2005) and Dürr and Watson (2010).

This biomass of fouling will attract a variety of organisms, including fishes, which, in turn, may attract other fishes. Oakes and Pondella (2009) found that not only was the abundance and diversity of fishes increased by the presence of cage structures in California, but also that the trophic structure of those fish communities differed from those from near-by kelp beds at 3 positions in the water column. In short, there was a shift towards crushers and pickers at cage sites, suggesting the importance of the fouling community on the cage structures to the shift in fish community composition and abundance. This suggests that the physical structure attracts a certain suite of fish. However, it is also likely that a large proportion of the wild fish associated with a site are present because of the abundance of excess feed added to the surrounding environment. To separate these two possibilities, Tuya *et al.* (2006) studied the fish associated with a net cage in the Canary Islands by doing surveys on 4 dates prior to and four dates following the removal of fish and feeding (but leaving the cage structure in place). The abundance of most species declined markedly following removal of fish and feeding but the abundance of several groups remained the same (herbivores, benthic macro- and meso-carnivores), including one (benthic macro-carnivores) that remained in greater abundances than in control locations, suggesting that they were present because of the structure provided.

Other mechanisms that attract and repel fish and other organisms from fish farm sites include lights and noise; information on these factors may be found in recent reviews by Trippel (2010) and Olesiuk *et al.* (2010), respectively. There is a wealth of information on how organic loading may modify benthic (mostly infaunal) communities (e.g. Hargrave 2010) and how these changes and the addition of physical structure may impact seagrasses below net pen farms. In general, benthic impacts are typically greatest directly below farms and there may be a stimulatory effect on benthic infaunal biomass and diversity at intermediate distances. Clearly, modification of these communities may attract or repel fish and other organisms, depending on the species' specific ecology. These effects have not been well examined.

Effects of fish farms upon wild fish fitness and population effects

Biomass. Aggregations of wild fish around fish farms may have a variety of population-level effects on wild fishes. As outlined by Uglem *et al.* (2014), given that 1.3 % of the 1.6 M t of feed used in for the salmon farming industry has been estimated to be consumed by wild saithe, this suggests that the biomass of this fish may have increased by ca. 21 000 t since the onset of farming. How this increase in biomass impacts the population of this species and the fitess of individuals remains unclear.

Condition. Fish farms may represent high quality habitats for wild fish because of the availability of artificial food with high energy content (Vita *et al.* 2004). For example, there is some evidence that the relative gonad mass of salmon farm-associated fish is greater than that of fish from reference areas (Dempster *et al.* 2011). Likewise, the same study also showed that the condition index and hepatosomatic index of both farm-associated saithe and cod are greater at farm sites than reference areas. Together, these measures suggest that the fitness of those fishes aggregated around fish farm sites may be greater than that of fishes in areas distant from farms. Similarly, Fernandez-Jover *et al.* (2011b) also found elevated body and liver condition of cod and saithe in both of two and one of two studied locations, respectively. In addition, fatty acid compostion of both body and liver tissues were modified at farm sites relative to reference sites, reflecting the terrestrial nature of some of the fish meal ingredients. Both of these studies suggest that fish farms provide a significant trophic subsidy to wild fish that feed on lost feed. Fernandez-Jover *et al.* (2007) examined the physiology of Mediterranean horse mackerel (*Trachurus mediterraneus*) that aggregate around two sea-bass (*Dicentrarchus labrax*) and sea-bream (*Sparus aurata*) farms relative to those in reference areas. These fish also had higher body fat content than fish in reference areas, suggesting that their increased condition could increase their spawning ability, and their fatty acid composition was modified. The implication of these modification of fish populations and communities in terms of health status and reproductive potential remain poorly understood (Fernandez-Jover *et al.* 2011a).

Fitness of animals, gametes, and larvae. As mentionned above, typical measures of fish condition, including condition indices and hepatosomatic indices, are often greater in fishes that aggregate around fish farms, and are typically correlated with spawning success (Fernandez-Jover *et al.* 2011a). However, as pointed out by Fernandez-Jover *et al.* (2011a), modified fatty acid composition may impact reproductive success, potentially reducing growth, egg quality, fecudity, and larval survival. Although Jørstad *et al.* (2008) and van der Meeren *et al.* (2012) have found that cod from adults reared in netpens may survive and become a de facto part of the wild population, Uglem *et al.* (2012) have shown that they also have reduced reproductive viability relative to cod fed on natural feed and suggest that this is due to nutritional deficiencies. A recent study examined the effect of fish farms on the growth of newly recruited fishes and found that some species that aggregate at fish farms along the Mediterranean coast of Spain have altered growth relative to fish recruiting to natural reefs, suggesting that differences in otilith structure are due to the consumption of aquafeeds from the farms (Fernandez-Jover & Sanchez-Jerez 2015). Dempster *et al.* (2011) suggested that fish farms may act as reproductive sources for wild fish populations, provided the fish are protected from fishing while resident near farms to allow increased condition to manifest in greater reproductive output. On the other hand, studies also indicate that fish farms may interfere with spawning behaviour, as indicated for Atlantic cod (Bjørn *et al.* 2009).

Migration patterns. A number of lines of evidence suggest that fish farms may alter the movement and migration patterns of fishes aggregated around them. For example, given the range of studies that have described aggregations of fishes at various spatial scales around fish farms (see above), it is evident that these operations alter fish movement at at leat this spatial scale. Although earlyy studies on the movement of saithe found that salmon farming has not influenced seasonal migration patterns (Bjordal & Skar 1992), more recent work has found conflicting results. Otterå & Skilbrei (2014) did a combined hydroacoustic and T-bar tagging study to examine the movement of saithe around salmon farms in Norway and found that while many fish continue to undertake normal migration patterns, many others do not migrate offshore and remain in the farm area for much of the year, although they may move often betweeen farm sites, as was also noted by Uglem *et al.* (2009). Likewise, Arechavala-Lopez *et al.* (2010), also using hydroacoustic tagging methods, showed that grey mullet that aggregate around sea bream and sea bass farms also move rapidly among farm sites and are similarly connected to populations on fishing grounds in the western Mediterranean Sea. Work done in the Red Sea shows that the suite of species associated with fish farms there were more typically assocaited with coral reefs, which were >4 km distant from cage sites, suggesting that the farms modified the distribution of these species.

Anecdotal evidence from fishermen in Norway suggests that migrating cod have changed their spawning migratory behaviour since the establishment of salmon farms in some areas. To evaluate if this is due to olfactory cues, Bjørn *et al.* (2009) examined the movement of released cod half of which had their olfactory sense blocked. They found no difference in migration rates (there was very little) but could not discount the proposed olfactory mechanism. Likewise, fishermen in the Bay of Fundy, eastern Canada, have also suggested that herring and gravid female lobster avoid areas where salmon aquaculture has become established (Wiber *et al.* 2012)

Effects of fish-farm interactions upon wild fishery landings

Concentration. As pointed out above, fish farms tend to aggregate fishes around them at various temporal and spatial scales. In many locations, such as Norway (Dempster *et al.* 2010), these fish are to some extent protected from fishing pressure through legal instruments or simply practical issues (such as fishing is not possible as gear will become fouled in farm infrastructure). In other locations, fish may be at greater risk of capture as they are concentrated in smaller areas. Indeed, Bacher & Gordoa (2015) suggest that artisanal fishing within farm areas may impact the abundance of fish there as may commercial fishing, even though the latter occurs some distance from farms. Likewise, Izquierdo-Gomez *et al.* (2014) found that fish caught from directly around farm sites by small-scale artisanal fishers had the lipid signature of fish that had fed on aquafeeds whereas fish caught from trawled fisheries some distance further away from the farms did not. Anecdotal evidence from many areas suggest that recreational fishers often congregate around net pens as they are known to have greater density of fish associated with them than the general area in which they are in. Arechavala-Lopez *et al.* (2010) conducted the first study using hydroacoustic tagging of wild fish around Mediterranean fish farms and demonstrated that offshore aquaculture farms and local fishing grounds in the western Mediterranean Sea are connected through movements of wild fish. They concluded that these farms attract and affect large numbers of commercially-important fish species, probably causing ecological changes, not only in the immediate proximity of farms, but also several kilometers away from the farms. Other studies have found similar patterns elsewhere (e.g. Giannoulaki *et al.* 2005, Arechavala-Lopez *et al.* 2011, Goodbrand *et al.* 2013). Machias *et al.* (2006) further suggest that increased abundances due to the trophic subsidy provided by finfish net culture may increase fisheries landings.

Condition. In addition, fish farms may positively impact the condition of fishes that are associated with them. However, in some areas, this may mean that these fish may be caught in some sort of ecological trap whereby short-term gains in fitness due to trophic benefits from waste feed or associated prey species may be greatly off-set by increased susceptibility to capture by commercial or recreational fishing (Fernandez-Jover *et al.* 2008). For example, Sanchez-Jerez *et al.* (2011) suggest that commercial and recreational fishing has increased around fish farms in the Mediterranean part of Spain. In addition, many other fish species with isotopic signatures that suggest they are trophically connected to fish farms have been observed in fisheries catches (Arechavala-Lopez *et al.* 2011, Izquierdo-Gomez *et al.* 2014).

Given the above, a number of authors have suggested that fish farms be managed somewhat like marine protected areas (MPAs) to ensure that they continue to contribute to wild stocks through increased biomass and related parameters (e.g. Dempster *et al.* 2002, Dempster *et al.* 2005, Dempster & Sanchez-Jerez 2008, Arechavala-Lopez *et al.* 2013, Özgül & Angel 2013).

Effects of fish-farm interactions upon wild fish quality

It has been suggested that the quality of a variety of species of fish that have been eating aquafeeds around fish farms have reduced flesh quality. As pointed out above, many fish that aggregate around fish farms do so for the waste feed and thus have modified lipid signatures and this has been suggested to be the causative factor. For example, saithe populations are particularly numerous around salmon cages in northern Europe (Dempster *et al.* 2010) and may obtain a significant proportion of their diet from waste feed (Uglem *et al.* 2014). This has been suggested to increase the body and liver condition of gadoids around fish farms in Norway, including increasing the concentration of terrestrial-derived fatty acids and decreasing the concentration of docosahexaenoic acid (DHA) in the flesh and liver of these fish (Fernandez-Jover *et al.* 2011b). Fernandez-Jover *et al.* (2007) examined Mediterranean horse mackerel around sea bass and sea bream farms in the Mediterranean and found that fish from farm sites had elevated fat content and altered fatty acid composition, relative to those from areas distant from fish farms. These authors and others (e.g. Ramírez *et al.* 2013) have thus suggested that fatty acid composition could also serve as a biomarker to infer the influence of a fish farm on the local fish community, helping to better describe these perceived environmental consequences of fish farming. More recently, Izquierdo-Gomez *et al.* (Izquierdo-Gomez *et al.*) examined total lipid content and fatty acid profiles from four species of fish around Mediterranean fish farms. In most cases, fish from up to around 10 km distant from farms differed in both respects from fish caught further away from farms. Feeding on aquafeeds has also been shown experimentally to impact saithe skin and muscle colour, pH, fatty acid composition, and sensory parameters relative to wild-caught fish (Skog *et al.* 2003, Otterå *et al.* 2009). In all these studies, it is unclear what impact altered total fat content and fatty acid profiles may have on the physiology and fitness of the fish.

Chemical inputs from salmon aquaculture may include antifoulants, antibiotics, parasiticides, anaesthetics, and disinfectants. Burridge *et al.* (2010a) published an overview of the use and potential effects of these compounds for the four major salmon-producing nations: Norway, Chile, UK, and Canada. Antimicrobial resistance in bacteria in response to antibiotic use on fish farms was discussed by Grigorakis & Rigos (2011), and identified as a risk factor that should be considered (Burridge *et al.* 2010b, Buschmann *et al.* 2012).

A study by Bustnes *et al.* (2011) did not support the notion that salmon farms in general increase the concentrations of potentially harmful elements in wild fish, and further, the distribution of Hg and other elements in cod and saithe in Norwegian coastal waters may be more influenced by habitat use, diet, geochemical conditions, and water chemistry than association with fish farming practices.

Fernandez-Jover *et al.* (2007) showed that *Trachurus mediterraneus* feeding around salmon cages had a significantly higher body fat content than control fish from a more distant location. The fatty acid composition also differed between farm-associated and control fish.

Other effects of fish-farm interactions on wild fish (and other) populations

In addition to the larger fish, including some commercially important species (Valle *et al.* 2007), that are attracted to feed and smaller fishes associated with finfish farms, so too may be birds and marine mammals. For example, a series of studies headed by Díaz

López (Díaz López *et al.* 2005, Díaz López 2006, Díaz López & Bernal Shirai 2007, Díaz López *et al.* 2008) have shown that dolphins *Tursiops truncatus* are attracted to fish cages in Italy because of the large number of fishes, on which they feed, that are attracted to the net structures. These same authors have shown that the dolphins have also changed their social structure, switching from hunting mostly cooperatively to hunting individually and opportunistically, to take advantage of the aggregation of fishes around the fish cages. They are also apparently able to modify hunting tactics to respond to prey densities around fish farms (Díaz López 2009). Bearzi *et al.* (2009) discuss these studies at length. Elsewhere, Ribeiro *et al.* (2007) suggest that the spatial distribution and habitat use by Chilean Dolphins *Cephalorhynchus eutropia* is not influenced by the presence of salmon cage farms in Chiloé Island, Chile. Seals and sea lions are also attracted to fish farms and have been recorded to be more abundant around them than similar areas without fish farms (Nelson *et al.* 2006, Sanchez-Jerez *et al.* 2011, Northridge *et al.* 2013). Likewise, otters may also be attracted to these sources of food (Sales-Luis *et al.* 2013).

Trapping in anti-predator netting. As pointed out above, finfish culture farms offer predators a tempting source of potential food (both farmed and associated fish) and many take advantage of this. Thus many farms use anti-predator netting to reduce the impacts of these animals on their stock. Given that such predators may easily become entangled in the vast array of nets and other hardware in the water column in fish farms, a number of authors have also highlighted the importance of potential entanglement of seals and other marine mammals, birds, and sharks by the physical structure associated with fish cage aquaculture (Kemper & Gibbs 2001, Tlusty *et al.* 2001), e.g., Würsig and Gailey (2002), (Forrest *et al.* 2007, Ribeiro *et al.* 2007). Data on this are rarely quantitative and the extent of the problem is poorly known. In one rare exception, in a 15 month survey in Italy, Díaz López and Bernal Shirai (2007) observed an average entanglement rate of 1 dolphin per month for cages with loose anti-predator netting and 0 for those with taught anti-predator netting. As visitations by dolphins to fish cage sites in the area where this study was done seem to be increasing with the number of farms (Bearzi *et al.* 2009), such encounters may become more common. Historic California sea lion deaths due to finfish cage aquaculture entanglements in British Columbia increased from 1994 (the first year with data) and then declined over the period 2000 through 2004 (the last year with data, see Table 6) (Anonymous 2000, 2003, 2007), largely due to better weighting practices attain proper net tension. Similarly, minimum estimates (i.e., from self-reporting) of harbour seal entanglements in Washington over the period 1997 through 2001 declined from 15 in 1997, to 5 in 1998, and to zero thereafter (Carretta *et al.* 2009). Unpublished data (G. Perry, pers. comm.) suggests that 60 to 70 and ca. 30 sharks and tuna were trapped by Newfoundland finfish cage aquaculture installations in 2008 and 2009, respectively. Likewise, a variety of seabirds may also become similarly entangled in anti-predator netting or otherwise killed from various practices associated with finfish net pen aquaculture (Carss 1993, 1994).

Interaction between shellfish farms and wild populations

Aspects not covered here: this document assumes that planktonic organisms are not capable of responding to cues effectively at relevant spatial scales, i.e., cannot be attracted, but can actively settle when encountering a farm by chance.

There are two main general mechanisms by which mussel and other bivalve aquaculture activities attract and repel wild populations. The first is the addition of physical structure to the environment. This includes the farm infrastructure as well as the shellstock that is being grown, which also provides hard biogenic substrate for a variety of organisms. Second is the addition or modification of food resources in an area in the form of the farmed organisms themselves, the organisms growing on or otherwise associated with the farm infrastructure or product, and modifications to the benthic environment. Farm husbandry activities may also influence the degree to which various organisms are attracted or repulsed by farm sites. Here, we provide an overview of the relations between bivalve aquaculture and wild populations of marine and coastal organisms. To this end, we evaluate the attractive and repulsion effects attributable to infrastructure and the farmed product – to the extent possible. We include what are thought to be largely physical effects (including fouling) in the infrastructure sections and emphasize effects caused specifically by presence of the farmed product in the sections referring to effects attributable to the farmed shellfish. We also include sections related to ongoing husbandry effects that otherwise are not specifically related to the farm infrastructure or farmed bivalves.

Attraction of wild populations by shellfish farm infrastructure

Shellfish aquaculture (including bottom culture without cages, bags, or lines) introduces considerable hard physical structure into an environment where such structure may be limiting (Moroney & Walker 1999, Carman *et al.* 2010, McKindsey *et al.* 2011) . In the cases of caged or suspended shellfish farms, even in the absence of shellfish themselves, the physical farm infrastructure (buoys, ropes, anchors, etc.) provide attachment for substrate-requiring organisms from a wide range of taxa, including macroalgae, bryozoans, other mollusks, and tunicates (Willemsen 2005). These organisms thus form the biological components of artificial reef-like structures to which fish and invertebrate predators are attracted (Costa-Pierce & Bridger 2002). Often, it is not clear to what extent predators are attracted to the structure itself (as cover from higher trophic level predators) or to the prey associated with the structure (Würsig & Gailey 2002).

Water column. Fouling is the bane of the aquaculture industry (Dürr & Watson 2010, Fitridge *et al.* 2012) and there is abundant literature on the fouling associated with bivalve culture, including its ecological effects (see reviews in Dumbauld *et al.* 2009, Forrest *et al.* 2009, McKindsey 2011, Lacoste & Gaertner-Mazouni 2014). In summary, addition of physical structure in the water column allows for the development of substantial fouling communities in the water column that have a structure similar to that of natural reefs. Together, the physical structure and associated organisms may then attract fishes and other large organisms. For example, Brooks (2000) and Carbines (1993) describe a diversity of fishes that are attracted to farm sites as they feed on the mussel line-associated communities. Brehmer *et al.* (2003) examined the distribution of fish and fish schools in a French Mediterranean longline mussel growing area and found a greater number, but smaller size, of fish schools within mussel culture sites than outside of the sites. Šegvić-Bubić *et al.* (2011) report that some fish that frequent mussel sites in Croatia were there because they hunted farm-associated fishes. Dealteris *et al.* (2004) found a greater abundance and diversity of fishes and mobile invertebrates associated with rack and bag oyster culture than with either seagrass or sand locations in Rhode Island and attributed this to the former having the greatest habitat value for these organisms. Also working on rack and bag oyster culture in Rhode Island, Tallman and Forrester (2007) found that some species of fish were more abundant in culture sites than either natural or artificial reefs, suggesting that this habitat was attractive for these species. Similar results were found in Delaware for rack and bag oyster culture (Erbland & Ozbay 2008) and for floating oyster bag culture (Marenghi *et al.* 2010). In France, an experimental study has determined the use of rack oyster-rearing structures as resting sites during day time for *Solea solea* (Laffargue *et al.* 2006).

Bottom. Fixed benthic structures include bags used for oyster or clam culture, on-bottom anti-predator covers used for infaunal clams, PVC tubes for outplanting large individual clams, and anchoring systems. In addition, large amounts of litter from bivalve culture may also be found on the seabed under mussel farms and on nearby shores (Cole 2002). There is limited information on how benthic physical structure associated with bivalve aquaculture may act to attract wild populations of fishes and other groups. There is considerable information, however, on the importance of artificial structures used as reefs to enhance specific areas for fisheries species (e.g. Jensen *et al.* 2000, Seaman 2000, Brickhill *et al.* 2005), and this may inform assessment of the importance of benthic structure in aquaculture. In general, benthic structures may provide considerable surface area for sessile and other hard-substrate associated organisms that are not normally found on soft sediment bottoms, as is often the case in coastal embayments where bivalve aquaculture is practiced. Thus, diverse fouling communities may develop on benthic farm structures (e.g. Carbines 1993, Powers *et al.* 2007, Washington Sea Grant 2013) that serve as appropriate habitat for fish and other taxa. An experimental study showed that lobster *Homarus americanus* were attracted to the presence of cement anchor blocks used in mussel farms in eastern Canada rather than to mussel fall-off *per se* (Drouin *et al.* 2015). In Washington, the abundance of transient fish and macroinvertebrates in geoguck *Panopea generosa* sites with outplanting structures was twice that observed in reference areas, suggesting that some groups were attracted to the physical structure provided or to the organisms associated with it (Washington Sea Grant 2013). A study by Powers *et al.* (2007) suggested that the increased abundance of structural species (macroalgae and some erect epifauna) growing on quahog *Mercenaria mercenaria* grow-out bags in North Carolina increased the abundance and diversity of associated macrofauna (fish and macroinvertebrates) from base-line levels observed in sandy habitats to at least as great as those found in near-by seagrass beds.

The accumulation of biogenic structure under bivalve farm sites from fall-off also may be considerable and add physical structure to the benthic environment. In Canada, Leonard (2004) showed that an average of 130 g m^{-2} of material fell daily to the bottom under mussel lines in îles de la Madeleine, Fréchette (2012) suggests that 59% of the total benthic organic loading from mussel culture is from fall-off, and Comeau *et al.* (2015) estimate that 89% of the spat seeded on mussel lines in Prince Edward Island is lost though fall-off prior to harvesting. In Scotland, shell hash from fallen mussels can dominate sediments

(Wilding & Nickell 2013). Kaspar *et al.* (1985), de Jong (1994), and Inglis and Gust (2003) reported the build-up of live mussels and shell material under mussel farms in New Zealand. Iglesias (1981) and Freire and González-Gurriarán (1995) also noted an abundance of mussels, shell, and shell fragments in the Ría de Arosa, Spain. Both of these types of benthic structure may provide habitat for benthic organisms requiring hard substrate or cover from predation. Given the importance of bivalves in general in creating conditions that attract a great diversity of organisms (Gutiérrez *et al.* 2003, Sousa *et al.* 2009), such accumulations on the bottom should also logically attract a variety of associated species. A number of these studies on mussel farm effects mention the rich communities that may be associated with these shell reefs but little work has quantified the attractiveness of these habitats to fishes and other groups.

For culture of bivalves on the bottom, such as oysters, the physical structure added also includes the shells of the farmed organisms, which may serve as hard habitat in areas where this may be limiting. For example, Trianni (1995) examined epifauna and infauna in habitat types in California and found that diversity was greater in sites with on-bottom oyster culture relative to one with a muddy bottom because of the increased abundance of epifauna associated with the oyster valves. A limited number of studies have shown greater diversities and abundances of fishes associated with on-bottom oyster sites relative to areas without structure and/or similar to those with some type of natural structure.

Attraction of wild populations by farmed shellfish themselves

Although plankton have been excluded from this listing, it is noteworthy that pathogens and parasites (and commensals, such as pea crabs) of cultivated shellfish find opportunities to proliferate on shellfish farms. These "reservoirs" of infective agents have been cited as threats to natural shellfish populations, but in reverse, natural shellfish populations can be thought of as increasing risk of disease in farmed populations.

Cultivated shellfish species have predators other than human beings in most environments where they are farmed. Thus, many organisms are attracted to bivalve farms because the farmed animals themselves are an attractive source of food. In addition to the bivalves on culture structures, many mussels may also fall off from culture structures and thus also become available to benthic predators. Thus, early studies on this in mussel farms found increased abundances of crabs and fishes in areas within mussel farms relative to areas without them (Tenore & González 1976, Chesney & Iglesias 1979, Romero *et al.* 1982). Subsequent work done in the same area (Freire *et al.* 1990, Freire & González-Gurriarán 1995) found that the diets of crabs there had shifted to contain a greater proportion of mussels, suggesting that the animals had moved to the mussel farming areas to obtain a trophic advantage.

Other predatory animals, such as seastars and gastropods, are also commonly more abundant within mussel farms relative to areas outside of them (Olaso Toca 1979, 1982, Inglis & Gust 2003, D'Amours *et al.* 2008). At times, effects are complicated by confounding factors. For example, a recent study by (Drouin *et al.* 2015) used observational and manipulative studies to suggest that the spatial distribution of the abundance of American lobster in and around a mussel farm in îles de la Madeleine, eastern Canada, was attributable to lobster being attracted to anchor blocks as refuges and to increased abundance of prey, including both fallen mussels and crabs that also feed on the mussels.

Gerlotto *et al.* (2001) report that the abundance of fish, particularly *Sparus auratus*, increased following the introduction of suspended mussel culture in the same area and attribute this to increased prey availability at the farm site as benthivorous fish were observed feeding on mussels in the mussel site. Likewise, Šegvić-Bubić *et al.* (2011) suggest that a variety of fishes are attracted to mussel longline sites in Croatia and that these are responsible for significant losses from mussel socks. This effect was also observed in the rias of Spain (Filgueira *et al.* 2007, Peteiro *et al.* 2010) and in New Zealand (see references in Schiel 2004).

Interactions with birds, marine mammals, and other non-fisheries species

A number sea birds are attracted to suspended bivalve culture sites because of the availability of food there (Meire 1993). For example, birds such as ducks and cormorants are known to hunt in and around farms (Dumbauld *et al.* 2009). There are two major feeding modes for birds on bivalves: the waders (plovers, oyster catchers and the like) and divers (scaup, scoters, etc.). The first group of birds may feed on bivalves growing in beach culture; whereas, the second group may consume bivalves being grown on the bottom at high tide and/or in suspension, depending upon the species. Bivalves in culture may provide a direct food source to many types of birds (Dankers & Zuidema 1995). In the case of suspension culture, Dunthorn (1971) and Davenport *et al.* (2003) suggest that mussels grown in culture 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.

Habitat changes associated with bivalve culture may also impact associated communities such that it may increase (or decreasee) the abundance of food for certain birds. For example, Caldow *et al.* (2003) experimentally manipulated the density of mussels in an intertidal mudflat and monitored the abundance of birds in the area. None of the species monitored dropped in abundance and some increased, especially in areas where the availability of one of their preferred prey items, the amphipod *Corophium volutator*, was greatest. Suspended bivalve culture sites are used as resting places for a variety of sea birds (Butler 2003). In an observational study, Roycroft *et al.* (2004) reported a greater number of species and abundance of birds in suspended mussel culture sites in Ireland than in a series of control sites. They suggest this was mainly attributable to the provision of perching areas (buoys, platforms, etc.) and to the diverse communities of organisms growing on the farm-associated gear offering an attractive food source for a variety of species. In fact, Boelens (cited in Roycroft *et al.* 2004) suggest that the influence of suspended mussel production is generally positive for bird communities.

Infaunal clam culture may also attract birds that may feed easily on large concentrations of these bivalves. This includes birds that feed at high tide (e.g. scoters) and at low tide (e.g. oyster catchers) (Hilgerloh & Siemoneit 1999, Godet *et al.* 2009, Žydelis *et al.* 2009). In some areas, this has led to vast expanses of beaches being covered with anti-predator netting (Spencer *et al.* 1996, Cigarría & Fernández 2000, Carswell *et al.* 2006, Toupoint *et al.* 2008, Bendell & Wan 2010).

Oyster aquaculture also seems to influence bird populations. For example, Kelly *et al.* (1996) examined the distribution of shorebirds in California relative to oyster culture sites and found some species to be attracted to, some repulsed by, and other not affected by the presence of oyster leases. Overall, the authors suggested that oyster aquaculture led to a net decrease in the abundance of shorebirds in the area studied. (Hilgerloh *et al.* 2001).

Marine mammals also may be attracted to bivalve farms. Although Würsig and Gailey (2002) suggest that the bivalve aquaculture industry suffers "significant losses" from river and sea otters, Nash *et al.* (2000) suggest that the risk of large crop losses is small. Seals and other pinnipeds may be attracted to mussel farms as they occasionally consume mussels as well as the benthic organisms that typically are associated with mussel farms, including crabs and fish (Roycroft *et al.* 2004).

It appears possible that large, swimming animals, such as marine mammals and possibly sea turtles, may avoid shellfish suspension-culture arrays because the lines may interfere with swimming (Mann & Janik 1999), thereby minimizing entanglement risks detailed below. The extensive nature of suspended bivalve culture may, however, displace marine mammals from habitat they otherwise would use. Markowitz *et al.* (2004) found that Dusky Dolphins (*Lagenorhynchus obscurus*) avoided areas occupied by mussel culture longlines in the Marlborough Sounds, New Zealand. (Würsig & Gailey 2002) suggest that this may be caused by the suspended structure inhibiting the ability of the dolphins to aggregate fish prey. Similarly, Pearson (2009) found that this same species in Admiralty Bay, New Zealand, modified its behaviour to avoid travelling within areas with suspended mussel culture. In Australia, Bottlenose Dolphins (*Tursiop* sp.) were reported to be excluded from parts of their home range by longlines for oyster culture (Watson-Capps & Mann 2005). Ribeiro *et al.* (2007) studied the distribution of Chilean Dolphins (*Cephalorhynchus eutropia*) in a bay in Chile and found that suspended mussel culture influenced dolphin habitat use such that the mammals spent less time than would be predicted (based upon surface area and habitat type) in areas with the greatest density of suspended mussel culture but were not less prevalent in areas with lower concentrations of mussel culture. Both area types were associated with foraging activities and not socializing or resting, suggesting that suspended bivalve culture modified dolphin habitat use within the area.

The physical structure added to the water column in suspended bivalve culture may be a hazard to marine mammals and sea birds, largely because of entanglement risk. Lloyd (2003) suggests that the risk of entanglement probably is greatest for thin ropes and those that are not under tension. Lloyd (2003) also suggests that baleen whales, which cannot echolocate, may be particularly susceptible to such entanglement. Thus more off-shore areas used for spat collection may also create hazards for whales. In an extreme example, Lloyd (2003) discusses how Bryde's Whales (*Balaenoptera brydei*) have been killed after becoming entangled in mussel spat collectors in New Zealand. There are no solid data on these potential effects, and it is not clear whether entanglement is a consequence of mammals being attracted to, or oblivious of shellfish-farming gear. The physical structure associated with bivalve farms may displace some species of sea birds, including diving duck and grebes, and anti-predator netting may trap birds (Pillay 2004, Varennes *et al.* 2013).

Control of crabs, fish, and birds (Caldow *et al.* 2003, Caldow *et al.* 2004, Goss-Custard *et al.* 2004, Žydelis *et al.* 2009) attempting to feed on cultivated shellfish can be accomplished using cages and/or suspension away from the benthic habitat of some predators, and various kinds of netting. Indeed, predator control introduces much of the structure causing the interactions listed above. In bottom culture, predators such as sea stars, crabs, and drills sometimes are controlled by trapping. The predators attracted to farmed shellfish must be controlled for the farming to be successful; aggregation of these predators near shellfish farms may reduce predation pressure on natural shellfish populations.

Attraction of organisms by shellfish farm operational activities

Activities associated with shellfish farm maintenance and operation include fouling control (Enright 1993, Adams *et al.* 2011), grading and thinning, and harvesting. Such activities can disturb the environment with human and machine activity such as noise and release of materials associated with the gear and the shellfish (fouling, biodeposits, dead shells, etc.). The release of fouling organisms and some farmed organisms into the environment typically attracts a variety of scavenging organisms such as crabs and other crustaceans, fish, and birds (D'Amours *et al.* 2008). This attraction helps to recycle materials and energy into the ecosystem’s trophic pathways. Although there is much anecdotal evidence of a variety of organisms being attracted by this fall-off, there has been very little quantitative data published on the subject.

Dredge harvest of bottom-cultured northern quahogs represents a disturbance of the benthic habitat, but consequences to sediment composition (re-suspension and wash-out of fine, organic particles and re-oxygenation) may improve habitat quality on medium time scales (Goldberg *et al.* 2014, Meseck *et al.* 2014). Benthic meiofauna are displaced, but this biological displacement is short-lived and less extensive spatially and temporally than repeated dredging of common-resource clam beds (Goldberg *et al.* 2012).

Ferns *et al.* (2000) noted that bird feeding activity increased following mechanical harvesting for cockles in Wales, with gulls and waders consuming the invertebrates that were made available by harvesting.

Recently, it has become apparent that various noises associated with farm husbandry (e.g. generator and engine) may induce a variety of sessile organisms to settle on hard substrates (e.g. Wilkens *et al.* 2012, McDonald *et al.* 2014, Stanley *et al.* 2014). This may encourage the development of fouling communities associated with mussel infrastructure and have consequent impacts on bivalve culture-environment interactions.

Repulsion of other organisms by shellfish farm functioning

Human activity, including motion, noise, and release of waste materials (engine exhaust, other emissions) stimulates alarm responses in many organisms, especially vertebrate species that have benefitted from avoiding potentially predatory humans. Accordingly, some marine mammals Becker *et al.* (2011; study results debunked by Marine Mammal Commission: http://www.ptreyeslight.com/article/seal-study-debunked-scientists) and birds (Varennes *et al.* 2013) may apparently be repulsed by farm operation activities, including devices deployed to this end. The main evidence for this is the effectiveness (to varying degrees) of sounds to repel predators on the shellfish themselves. Conversely, there is evidence of acclimatization to such human activities by birds and marine mammals following repeated exposure. Work has also shown that some predators, such as crabs, may be repulsed and have their foraging activities impacted by vessel noise (Wale *et al.* 2013) and thus normal husbandry operations may impact the distribution of these organisms through this mechanism.

In contrast to the attraction effects of harvesting discussed above, a number of studies have suggested that harvesting bivalves may have a repulsive effect on bird populations. For example, Spencer *et al.* (1998) suggest that harvest of Manila clam will impact infaunal communities with consequent effects on the distribution of bird populations.

Repulsion of other organisms by farmed shellfish themselves

This review found no evidence for repulsion of other organisms by farmed shellfish themselves.

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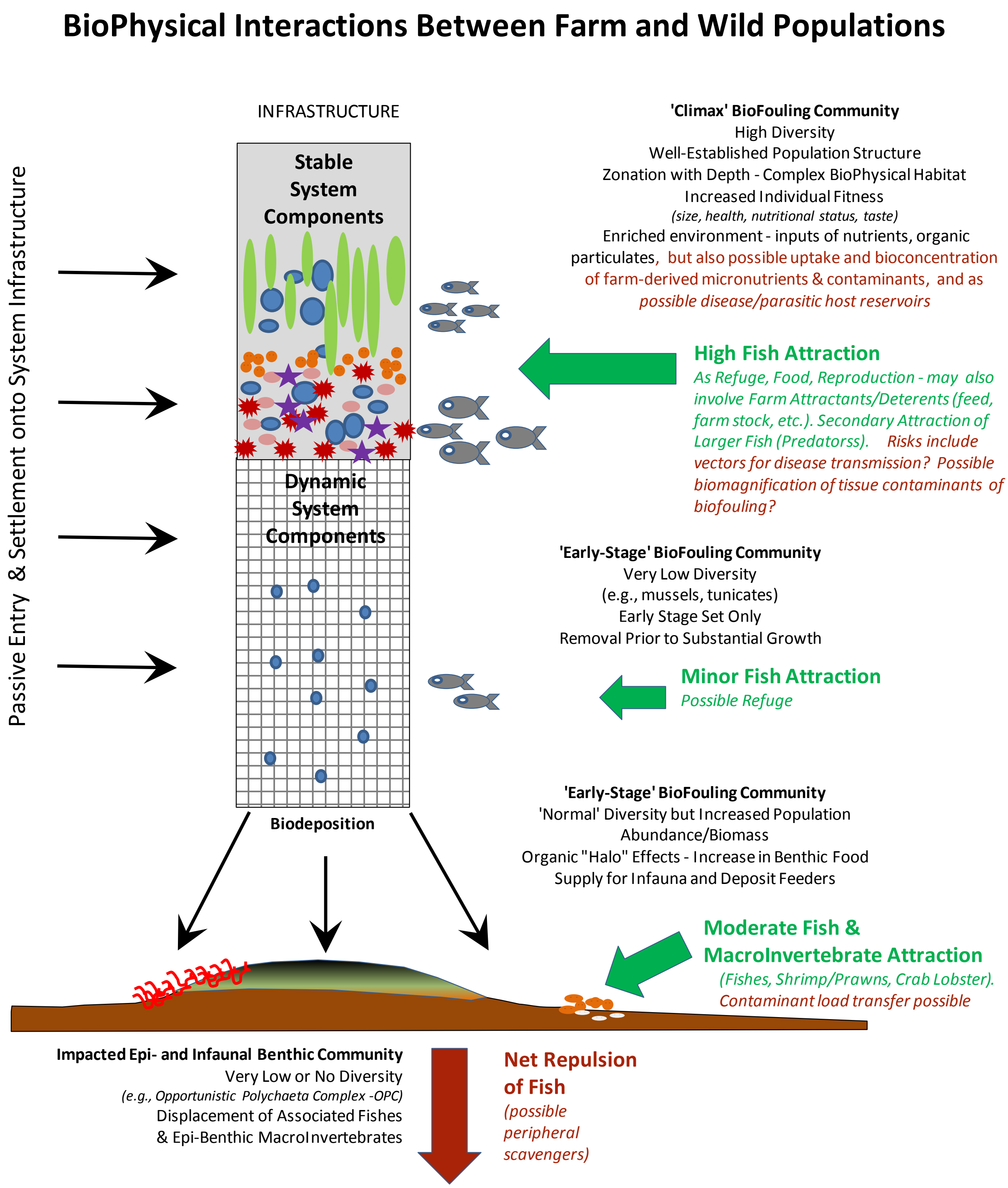
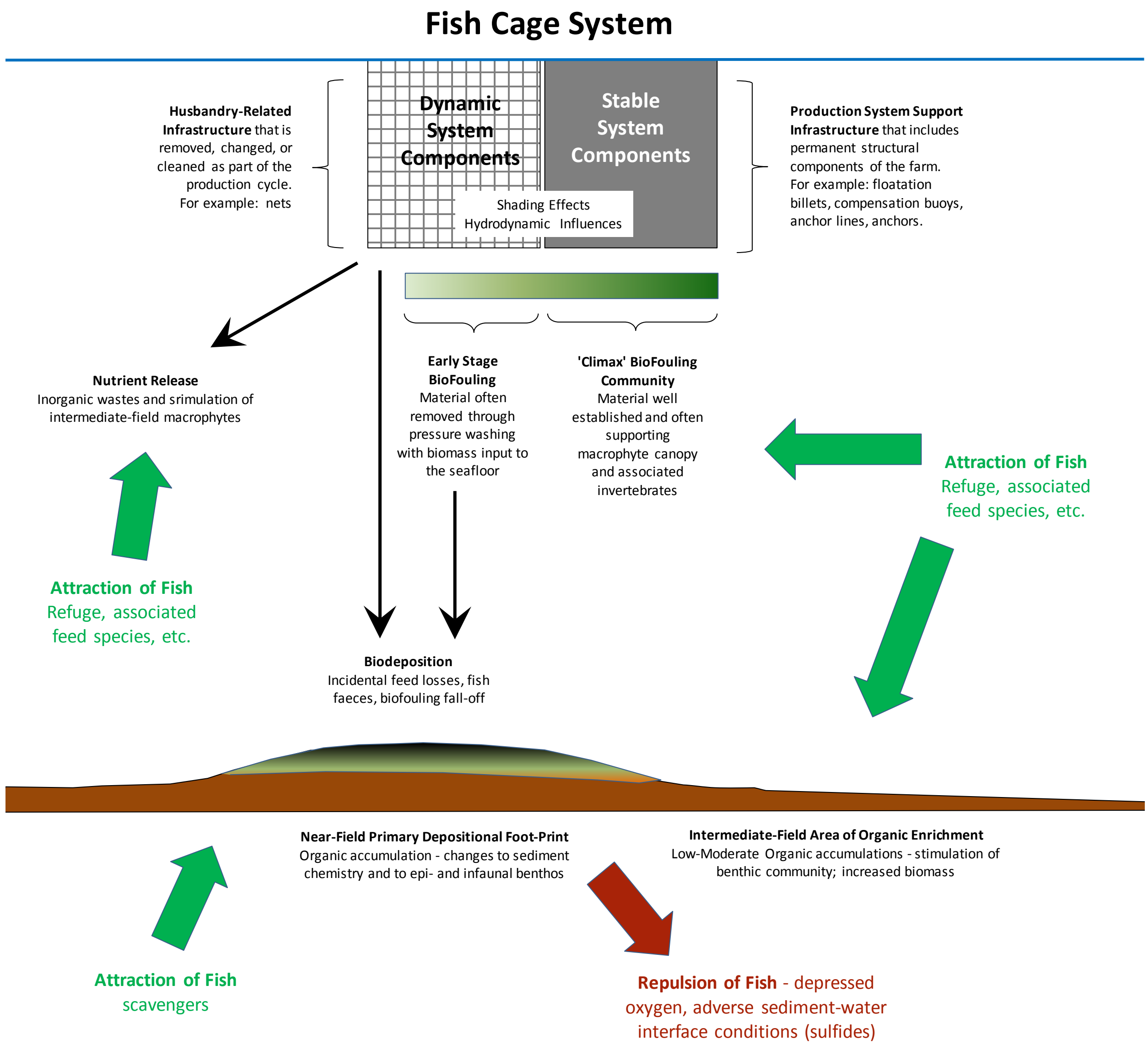
Table 1. Mechanisms proposed to explain floating and stationary Fish Attraction Devices (FAD's), and their applicability to inland water cage and pen structures (from Beveridge 1984). Note that only water column effects are considered; benthic effects (including feed pellet and other organic loading, benthic community modifications) are not. -, *, and ** indicate the mechanism has little, some, and considerable probable importance.

Mechanism	Applicability
Use as cleaning stations where external parasites of pelagic fishes can be removed by other fishes	-
Shade	*
Creates shadow areas in which zooplankton become more visible	*
Provides substrate for egg laying	-
Drifting object serves as schooling companion	-
Provides spatial reference around which fishes could orient in an otherwise unstructured environment	*
Provides shelter from predators for small fishes	**
Attracts larger fishes because of presence of smaller fishes	**
Acts as substrate for plant and animal growth, thus attracting grazing fishes	**

Table 2. Marine mammal mortalities due to entanglement with gear used in finfish (salmon) cage aquaculture in western North America, 1994-2004. All data is from NOAA (Anonymous 2000, 2003, 2007, Carretta *et al*. 2009). Double numbers for 2000 sea lion counts represents discrepancies between published reports. "-" indicates that data is not available.

Year	California sea lions		Harbour seals
	British Columbia (observed)	Washington (estimated)	Washington (estimated)
1994	13	-	-
1995	23	-	-
1996	54	4	-
1997	52	9	10
1998	88	9	5
1999	134	-	0
2000	217 / 225	-	0
2001	88	-	0
2002	19	-	-
2003	14	-	-
2004	6	-	-


BioPhysical Interactions Between Farm and Wild Populations
INFRASTRUCTURE
Passive Entry & Settlement onto System Infrastructure
Stable System Components
Dynamic System Components
Biodeposition
'Climax' BioFouling Community
High Diversity
Well-Established Population Structure
Zonation with Depth - Complex BioPhysical Habitat
Increased Individual Fitness
(size, health, nutritional status, taste)
Enriched environment - inputs of nutrients, organic particulates, but also possible uptake and bioconcentration of farm-derived micronutrients & contaminants, and as possible disease/parasitic host reservoirs
High Fish Attraction
As Refuge, Food, Reproduction - may also involve Farm Attractants/Deterents (feed, farm stock, etc.). Secondary Attraction of Larger Fish (Predatorss). Risks include vectors for disease transmission? Possible biomagnification of tissue contaminants of biofouling?
'Early-Stage' BioFouling Community
Very Low Diversity
(e.g., mussels, tunicates)
Early Stage Set Only
Removal Prior to Substantial Growth
Minor Fish Attraction
Possible Refuge
'Early-Stage' BioFouling Community
'Normal' Diversity but Increased Population Abundance/Biomass
Organic "Halo" Effects - Increase in Benthic Food Supply for Infauna and Deposit Feeders
Moderate Fish & MacroInvertebrate Attraction
(Fishes, Shrimp/Prawns, Crab Lobster). Contaminant load transfer possible
Impacted Epi- and Infaunal Benthic Community
Very Low or No Diversity
(e.g., Opportunistic Polychaeta Complex -OPC)
Displacement of Associated Fishes & Epi-Benthic MacroInvertebrates
Net Repulsion of Fish
(possible peripheral scavengers)


Fish Cage System
Husbandry-Related Infrastructure that is removed, changed, or cleaned as part of the production cycle. For example: nets
Dynamic System Components
Stable System Components
Shading Effects
Hydrodynamic Influences
Production System Support Infrastructure that includes permanent structural components of the farm. For example: floatation billets, compensation buoys, anchor lines, anchors.
Nutrient Release
Inorganic wastes and srimulation of intermediate-field macrophytes
Early Stage BioFouling
Material often removed through pressure washing with biomass input to the seafloor
'Climax' BioFouling Community
Material well established and often supporting macrophyte canopy and associated invertebrates
Attraction of Fish
Refuge, associated feed species, etc.
Attraction of Fish
Refuge, associated feed species, etc.
Biodeposition
Incidental feed losses, fish faeces, biofouling fall-off
Near-Field Primary Depositional Foot-Print
Organic accumulation - changes to sediment chemistry and to epi- and infaunal benthos
Intermediate-Field Area of Organic Enrichment
Low-Moderate Organic accumulations - stimulation of benthic community; increased biomass
Attraction of Fish
scavengers
Repulsion of Fish - depressed oxygen, adverse sediment-water interface conditions (sulfides)

Categorizing the Ecosystem Services Associated with Aquaculture

Cataloging ecosystems services – a framework

The United Nations Millennium Ecosystem Assessment developed a scheme to categorize the benefits of ecosystems (UNEP, 2005). The four categories of benefits include: provisioning, regulating, cultural, and supporting services (i.e. ecosystem services; Figure 1). Provisioning services are products obtained from ecosystems. Regulating services are the benefits obtained from the regulation of ecosystem processes, such as water purification and erosion control. Cultural services are nonmaterial benefits obtained from ecosystems, such as recreational or educational opportunities, or a "sense of place." Supporting services are necessary for the maintenance of other ecosystem services. Examples of supporting services include habitat formation, and nutrient cycling.

Framing the topic of ecosystem services associated with aquaculture is essentially an exercise in examining the interactions of aquaculture and the environment in the context of the ecosystem where these systems exist. For example the fecal waste from cultured organisms to a system is commonly viewed as a stressor that can overwhelm the assimilative capacity of the system, leading to eutrophic conditions, hypoxia, low oxygen and loss of diversity. In an oligotrophic system, these same additions of fecal wastes can stimulate productivity and increase diversity, providing a perceived valuable ecosystem service.

Similarly, the addition of structured habitat through aquaculture gear is commonly viewed as a regulating service that increases fish productivity and diversity, however in a system where reef-associated fish are not habitat limited, the addition of structure will have little or no value. Likewise, the value of the extractive culture of algae or filter-feeders that provide the service of mitigating eutrophication symptoms, will have little or no value in oligotrophic systems. In this review, we outline the fundamental issues for each of the four ecosystem services, as outlined by the UNEP, and provide examples of how each applies to the aquaculture context.

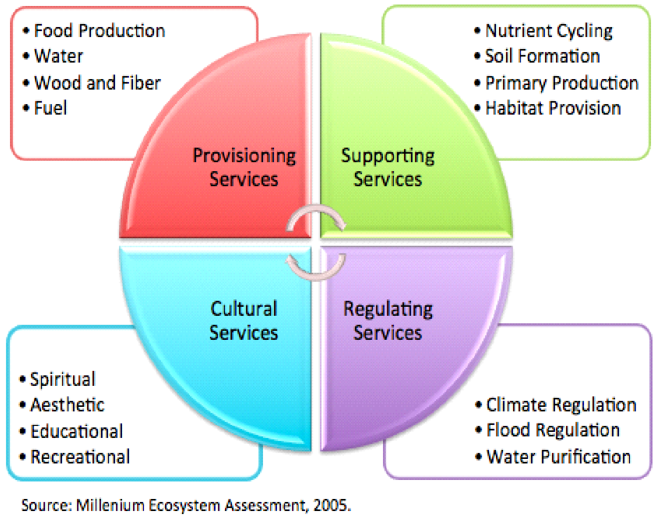


Figure 1. UN Millennium Ecosystem Assessment categories of ecosystem services.

Provisioning Services are products obtained from ecosystems.
Supporting Services are necessary for the production of all other ecosystem services.
Regulating Services are obtained from regulation of ecosystem processes.
Cultural Services are nonmaterial benefits obtained from ecosystems and their management.
Provisioning Services are products obtained from ecosystems. They include direct value of shellfish harvests and indirect value of dollars spent by firms and employees in the community (i.e. multiplier effect) (Burrage *et al.*, 1990). The release of shellfish for culture or sea ranching directly contributes to catch or unintentionally to enhancement of fisheries(Dao *et al.*, 1999). The value of larvae produced by the cultured stocks contributes directly to the wild fishery and indirectly influences fisheries enhancement (Grabowski *et al.*, 2012; Peterson *et al.*, 2003a).
Direct harvest, as a provisioning service, will vary greatly as a function of food availability, culture method, survival rate, and market price. For example, there is evidence that the market price of Gulf oyster is depressed by 30-50% over comparable products because of fears related to Vibrio bacteria (Keithly and Diop, 2001). Based on estimated on the density of sea stars at a Norwegian sea ranching site and average predation rates, the degree of loss of scallops indicated that scallop culture via sea ranching would not be economically viable and thus methods for reducing scallop predation by sea stars are necessary (Magnesen and Redmond, 2012).

Indirect value of dollars spent by firms and employees in the community is typically several times the farm-gate or dockside value of the harvest, causing a multiplier effect (Burrage *et al.*, 1990; Murray and Kirkley, 2004). Multipliers for fishing and aquaculture tend to be higher than for many other types of industries. Fishing, and farming (like mining, and software development) create "new wealth" unlike most other forms of commerce that simply transform goods or provide services.

Larval production may be an unintended provisioning service of shellfish culture. Unless the industry elects to use sterile triploid stocks, the shellfish will broadcast spawn millions of larvae into the surrounding waters each year. An adult female oyster might release 3-30 million eggs, and can do so several times a year. Those larvae will disperse with the tides for 14-21 days and will likely settle on public grounds. It is unlikely that the contribution to the wild larval pool will be significant unless the native wild population is severely depleted (ICES, 2014). Any attempt at valuating this service must take into account the high larval mortality and low recruitment success typical in this species.

Furthermore, farmers often opt to use selected lines of shellfish that have been bred for enhanced disease resistance while restoration practitioners tend to prefer to use native animals as broodstock. The genetic heterozygosity of cultured animals may be restricted in comparison to the wild genome. Fortunately, the risk of adverse genetic interactions between hatchery reared shellfish and wild stocks (both in restored and cultured populations) appears low (Cross *et al.*, 2008). Furthermore, farmers sometimes utilize polyploidy as a tool to prevent spawning and to ensure that assimilated energy is devoted to growth instead of reproduction. This would restrict some of the potential provisioning services of the cultured animals since they do not add to the population of wild larvae.

Fisheries enhancement through habitat enhancement may be another unintended service of aquaculture. Many have written of the increased value of recreational (Isaacs *et al.*, 2004) and commercial fisheries associated with oyster reef habitats (Lenihan and Grabowski, 1998). Peterson *et al.* (2003b) estimated that 10 m^2 of restored oyster reef in the southeast United States is expected to yield an additional 2.6 kg yr^{-1} of production of fish and large mobile crustaceans for the functional lifetime of the reef. Complex structure of aquaculture gear provides similar refugia for juveniles and attachment surfaces for fouling organisms that in turn become forage for larger fish and predators (Tallman and Forrester, 2007). Even the plastic mesh used over planted clams develops epiphytic growth and vertical structure similar to eelgrass, supporting similar assemblages of mobile fish and crustaceans (Powers *et al.*, 2007). Since these juveniles feed better and survive better than they might in unstructured habitats one can project the impact of the improved habitat on future fisheries recruitment and landings.

In addition, shellfish farms have been shown to enhance benthic-pelagic coupling, allowing benthic detritivores to access suspended particulate organic material from the water column. These detritivores (primarily amphipods and worms) form the base of the food chain for many fish species (Leguerrier *et al.*, 2004). Ulanowicz and Tuttle (1992) modeled the flow of nitrogen through food webs and predicted enhancing shellfish populations would increase benthic primary production, fish stocks and mesoplankton densities. They also noted that structured habitats are often limiting and suggested the introduction of oyster raft culture could replace limiting habitat for a host of other reef-associated species. Grabowski *et al.* (2007) estimated the value of commercial fisheries enhanced by the addition of restored oyster reefs was $4123/ha/y, however that was only if the oyster reef habitat was rare or limiting. Studies summarized by Coen *et al.* (1999), which included work in North Carolina, identified 72 facultative, resident and transient fish species in close proximity to oyster reefs. Kroeger and Guannel (2014) estimated the total annual net benefit from fisheries enhancement by the 2.37 ha of new reefs at $83,700-$89,300.

Supporting Services are necessary for the production of all other ecosystem services. They include processes such as nutrient cycling and habitat formation.

Filtration by suspension-feeders increases the rate of nutrient cycling. They capture suspended seston, assimilate organic matter and defecate refractory organic matter. Long-line mussel farming has been proposed for mitigation of excess nutrients in eutrophic coastal waters (Petersen *et al.*, 2014). Nutrient cycling enhances processes such as denitrification (Cerco and Noel, 2007; Newell, 2004; Newell *et al.*, 2002; Piehler and Smyth, 2011; Prins, 1998; Smaal, 2001) thus serving as a nitrogen sink in as part of the cultivation activity. Several researchers have shown how increased sedimentary carbon flux rates can stimulate bacterial denitrification (Cerco and Noel, 2007; Newell, 2004; Newell *et al.*, 2005; Newell *et al.*, 2002). In the Oosterschelde, estuary denitrification was shown to play a minor role in the nitrogen cycling related to mussel culture (Prins and Smaal, 1994). Other researchers have not been able to document similar denitrification rates associated with shellfish culture gear and there is a fairly large body of literature debating this question. These rates are likely to be highly variable seasonally and under various conditions of light, oxygen concentration, depth, and different culture methods. Unfortunately, in situ measurements are challenging so it may take some time to resolve the questions to make a firm estimate of the impact of aquaculture on the rate of denitrification. It is clear that wild and restored oyster reefs can occasionally stimulate impressive denitrification rates. For example, Piehler and Smyth (2011) found denitrification rates were higher in oyster reef and eelgrass habitats and this played an important role in coastal nutrient cycling. Piehler and Smyth (2011) estimated the annual cost to replace the nitrogen removal services provided by denitrification enhanced by oyster reefs and SAV at $3,000 per acre per year (based on the NC Nutrient Offset Credit Program value of $13/kg). Grabowski *et al.* (2012) estimated the nitrogen removal via denitrification at $1385-6716 per ha/yr not including the nitrogen removed at harvest in meat and shell. The alternative to using shellfish as nutrient extractors is more traditional methods to meet target nutrient reductions regulated by regional water quality standards are costly. The marginal cost of implementing tertiary treatment to large waste water treatment facilities in the U.S. has been calculated variously at $5.25/k N (Lindahl *et al.*, 2005) to as high as $138-$174/kg (Kessler, 2010).

Based on a full-scale mussel farm optimized for cost efficient nutrient removal in the eutrophic Skive Fjord, Denmark, Petersen *et al.* (2014) estimated the costs for nutrient removal to be 14.8 € per kg N making mitigation mussel production a cost-efficient measure compared to the most expensive land-based measures. The analysis of the costs related to establishment, maintenance and harvest revealed that mussel production optimized for mitigation can be carried out at a lower cost compared to mussel production for (human) consumption.

On a broader regional scale in the Baltic Sea, mussel farming as a potential supporting service to remove nutrients has been questioned due to the increase in oxygen demand from biodeposition by mussel farming and potential consequences for denitrification and reduced numbers of bioturbating organisms (Stadmark and Conley, 2011).

Shellfish culture may also act as a stabilizer in an ecosystem by increasing the time scale that nitrogen is stored/sequestered (Newell, 2004). Compared to pelagic grazers that is advected off coast, as shown for oysters *Crassostrea gigas* in the Thau lagoon (France) (Bacher *et al.*, 1995). A shellfish farm reduces the primary symptoms of eutrophication in that filter-feeders remove phytoplankton and organic detritus from the water column (Burkholder and Shumway, 2011; Cerco and Noel, 2005; Officer *et al.*, 1982). This increases light penetration and allow eelgrass to recover (Newell and Koch, 2004; Peterson and Heck, 1999). Increased light penetration can also stimulate micro-phytobenthos productivity (Newell *et al.*, 2005). The presence of filter feeders also speeds the cycling of suspended organic matter thereby removing the opportunity for bacterial mineralization, slowing the onset of secondary eutrophication symptoms such as hypoxia or anoxia (Ferreira *et al.*, 2011; Ulanowicz and Tuttle, 1992). Newell *et al.* (2007) argue explicitly that large populations of oysters would reduce summertime hypoxia.

In the Oosterschelde ecosystem, production of mussels (*Mytilus edulis*) was evaluated before and after completion of a large-scale coastal engineering project in 1987 which caused hydrodynamic and water-quality changes (Smaal, 2001). A change on how the mussel condition was affected by change in annual standing stock of shellfish indicated a positive feedbacks of the mussels in the Oosterschelde ecosystem—through their large filtration and nitrogen regeneration capacity, increased phytoplankton turnover. It was concluded that feedbacks by filter feeders and farmers have to be addressed in estimating the exploitation capacity of ecosystems.

The potential role of mussels in nutrient cycling and feedback on primary production may differ between ecosystems, as has been suggested for oligotrophic fjord systems in Norway compared to shallow eutrophic areas (Jansen *et al.*, 2012; Jansen *et al.*, 2011).

Phytoplankton productivity is enhanced by remineralized nutrients. Pietros and Rice (2003) demonstrated that large shellfish populations in mesocosms would enhance the remineralization of benthic nutrients, speeding the cycling of nutrients and the primary production of phytoplankton in the water column in comparison to mesocosms that had fewer shellfish.

Algae and shellfish aquaculture may decrease inorganic nutrients and suspended POC. When benthic detritivores are allowed access to suspended POC, they act to enhance benthic-pelagic coupling. Benthic detritivores, primarily amphipods and worms, form the base of the food chain for many fish species (Leguerrier *et al.*, 2004). Shellfish biodeposits have also been shown to fertilize eelgrass roots thereby also contributing to natural habitat enhancement (Newell *et al.*, 2005; Peterson and Heck Jr., 1999; Wisehart *et al.*, 2007). Furthermore, bioturbation from deposit feeders (polychaetes, seacucumbers) enhances remineralization (MacDonald *et al.*, 2013). There is evidence that bioturbation by deposit feeders, such as echinoderms and sea cucumbers, accelerates the remineralization of nitrogenous wastes by periodically injecting oxygen into hypoxic sediments (Aller, 1994) and that deposit-feeding sea cucumbers influence several bio/geochemical interactions that mitigate organic loading in marine sediments (MacTavish *et al.*, 2012).

Habitat alterations were discussed above as a providing a provisioning service through enhancing wild fisheries. Habitat alterations also act as a supporting service by promoting or enhancing other ecosystem functions. For example, habitat created by aquaculture gear may support wild population productivity. Aquaculture gear provides enhanced and complex vertical structure and firm substrate for the attachment of fouling organisms. aquaculture gear can contribute to enhanced prey availability by promoting an increase in epifauna, fouling organisms, and detritivores (Leguerrier *et al.*, 2004). Habitat also provides shelter from predators (Coen and Grizzle, 2007; Coen *et al.*, 2007; Tallman and Forrester, 2007). Oyster farms (including the bags, racks and cages) provide enhanced and complex vertical structure and firm substrate for the attachment of fouling organisms. Farming gear provides small spaces in which juvenile fish and crustaceans can seek refuge from predators. Even the plastic mesh used over planted clams develops epiphytic growth and vertical structure similar to eelgrass, supporting similar assemblages of mobile fish and crustaceans (Powers *et al.*, 2007). Additionally, gear attract a highly diverse assemblage of fish and crustaceans (Dealteris *et al.*, 2004; Ferraro and Cole, 2007; Lenihan and Grabowski, 1998; Tallman and Forrester, 2007; Ulanowicz and Tuttle, 1992). The fish that aggregate in aquaculture gear tend to survive better and grow as fast (Clynick *et al.*, 2008; D'Amours *et al.*, 2008; Tallman and Forrester, 2007). Several have implied that this enhanced habitat value leads to improved reproductive success and future commercial fisheries landings (Coen *et al.*, 2007; Grabowski *et al.*, 2012; Peterson *et al.*, 2003a).

Both aquaculture gear, and sometimes the aquaculture organism itself, create complex surfaces and substrates for other animals and plants (Dealteris *et al.*, 2004; Glancy *et al.*, 2003). For example, oyster shell forms a 3-dimensional emergent, complex, firm substrate with a variety of microhabitats for use by resident macrofauna (Dealteris *et al.*, 2004; Glancy *et al.*, 2003; Grabowski *et al.*, 2012; Harding and Mann, 2001; Harding and Mann, 1999; Lenihan, 1999). In many estuarine systems this ecotope is increasingly rare and in many cases is limiting for associated populations of fishes (Lehnert and Allen, 2002; Posey *et al.*, 1999). Firm substrate provides shelter from predators (Coen and Grizzle, 2007; Coen *et al.*, 2007). Red drum *Sciaenops ocellatus*, larvae had lower mortality in mesocosms containing simulated oyster reefs compared with other habitat types (Stuntz & Minello 2001). Shell also attracts a unique assemblage of epifauna and fouling organisms that in turn provide food. Oyster shell serves as spawning substrate for skilletfish *Gobiesox strumosus (Runyan, 1961)*, Florida blenny *Chasmodes saburrae* (Peters, 1981), feather blenny *Hypsoblennius hentz* (Breitburg 1999) and frillfin goby *Bathygobius soporator* (Peters, 1983).

When oysters die, the nutrients contained in their tissues and shell are released back into the local environment. Given that shellfish are roughly 1% N by weight, the harvest of a metric ton of shellfish through harvest removes about 10kg of nitrogen from the estuarine system (Lindahl and Kollberg, 2009; Stephenson and Shabman, 2011). In the case of farmed shellfish, the grower removes the nutrients at harvest and ensures that the ecosystem services are maintained by replanting seed for the next year's crop ensuring a sustainable replenishment of shellfish biomass and the associated structure and function.

Regulating Services are obtained from regulation of ecosystem processes. They include processes such as shoreline stabilization by wave attenuating structures (Borsjea *et al.*, 2011; Grabowski *et al.*, 2012; Meyer *et al.*, 1997; Piazza *et al.*, 2005), water filtration provided by shellfish (Grizzle *et al.*, 2006), reduction in risk of human exposure to pathogens (Jones *et al.*, 2001), increased ecosystem resilience through promoting biodiversity (Bullock *et al.*, 2011; Dealteris *et al.*, 2004; Ferraro and Cole, 2007), and reducing turbidity (Cerco and Noel, 2005; Jones *et al.*, 2001).

Aquaculture gear may act to stabilize shorelines through wave attenuation. While some have suggested that oyster reefs can reduce wave energy to the shoreline by as much as 50–99% (Grabowski *et al.*, 2012; Kroeger and Guannel, in prep; Scyphers *et al.*, 2008), the impacts of different types of aquaculture gear on wave energy attenuation, erosion and benthic stabilization is not well understood. A preliminary study showed that a double row of oyster racks at a beach site had a statistically significant wave attenuating effect during periods of rougher wave conditions (Niles *et al.*, 2013). The impacts will vary greatly depending on the nature of the waves, and the design and extent of the reefs or culture equipment. In cases where structures actually obviate the need for shoreline armoring then communities benefit from tremendous cost avoidance (Kroeger and Guannel, in prep). Grabowski *et al.* (2012) predicted that in those cases where homeowners were demanding protection from erosive forces, and where oyster reefs (or in this case oyster culture gear) "functions as perfect substitutes for human-made structures, one hectare of oyster reef habitat is estimated to provide $85,998 of annual value." Meyer *et al.* (1997) showed that oyster shell cultch could protect against marsh erosion (and accelerate sediment accretion) in the face of storms and boat wakes. Piazza *et al.* (2005) evaluated the potential for oyster reefs to stem coastal wave energy in Louisiana concluding that they may have value in low-energy environments, but probably are of limited value in high-energy environments.

Shellfish provide a service unique to other aquaculture species as they are filter feeders and large populations of filter feeding shellfish will reduce turbidity (Cerco and Noel, 2005; Jones *et al.*, 2001; Newell, 1988; Newell *et al.*, 2007). This potentially provides regulating services through a deepening of the euphotic zone and a decrease in hypoxia (Cerco and Noel, 2007; Newell *et al.*, 2002), which allows eelgrass to recover (Cerco and Noel, 2005; Cerco and Noel, 2007; Newell and Koch, 2004). In many estuaries declines in eelgrass have been linked to light limitation induced by nutrient-stimulated growth of phytoplankton, epiphytes and macrophytes (Short *et al.*, 1995). Several authors have pointed to the beneficial impacts of shellfish filter feeding on eelgrass (Cerco and Noel, 2005; Cerco and Noel, 2007; Newell and Koch, 2004). Johnston *et al.* (2002) used a Contingent Choice Survey to determine that Long Island residents valued an acre of eelgrass at $6-8,000/acre, however a Productivity Model analysis of the same population revealed a marginal value of only $1,065/acre. Thayer *et al.* (1978) estimated eelgrass habitat value at $33730/ha. Poor *et al.* (2006) calculated marginal implicit prices associated with a one milligram per liter change in total suspended solids and dissolved inorganic nitrogen at $1086 and $17,642, respectively.

Furthermore, reduced turbidity inhibits harmful algal blooms and the risk of human exposure to pathogens. Cerrato *et al.* (2004) speculated that large populations of filter-feeders graze down the peaks of algal blooms, preventing them from attaining the "critical mass" necessary to develop into large-scale events with broad-scale impacts. Jones *et al.* (2001) showed that oysters reduced turbidity and bacteria concentrations in shrimp pond effluent. A report by Czajkowski and Bin (2011) estimated that a 1% improvement in water clarity, evaluated at the mean value, increased mean home value in Southeast Florida by nearly 4%. Using Travel Cost models, Johnston *et al.* (2002) estimated the value that Long Islanders placed on being able to swim in the Peconics at over $12million.; boating at over $18 million.

Farmers periodically tend gear to control biofouling, maintain optimal stocking densities and eventually harvest the market size animals. The frequency of this maintenance varies greatly depending on species, gear type, season, fouling intensity, and husbandry practices. From a practical standpoint, the typical farmer is only able to tend a small fraction of his gear at any given time. For example, an oyster farmer works his gear in rotation on a 1-3 month cycle, meaning that some of his gear may be clean, but the majority of the gear is typically laden with varying amounts of fouling organisms. The impact of these pulse disturbances tend to be short-term and potentially analogous to storm events in natural systems; and the communities involved tend to be highly adapted to periodic disturbance (Dumbauld *et al.*, 2009).

Although some aquaculture activities may create punctuated disturbances, aquaculture can also increase ecosystem resilience through enhancement of biodiversity. It is well documented that natural and restored reefs and aquaculture equipment (Dealteris *et al.*, 2004) attracts a diverse assemblage of fish and crustaceans. It is also assumed that biodiversity is one of the keys to having a stable and resilient ecosystem (Bullock *et al.*, 2011; Dealteris *et al.*, 2004; Ferraro and Cole, 2007; Fisheries, 2008; UNEP, 2005). Placing measurable metrics on these qualities to establish a relationship between measures of biodiversity and system stability has not been attempted. While a stable and resilient ecosystem may be a stated desirable state or outcome, it may be challenging to evaluate that preference.

The Netherlands government implemented a policy on shellfish aquaculture activities in nature reserves to ensure the conservation, protection and development of natural values and human activities. Traditional activities, such as fishing, are allowed so long as no negative effects are caused and enough food is reserved for birds and other wildlife. To execute this strategy, the government and the shellfish agreed on co-management (Kamermans and Smaal, 2002).

Cultural Services are nonmaterial benefits obtained from ecosystems and their management. They contribute to a range of different types of values such as tacit, inspirational, scholarly, and pragmatic (Anthony, 2009). Cultural services are recognized as important and valuable and are being addressed in detail by WGSEDA. Here we only briefly mention a few aspects of cultural services.

Tacit values include things such as a sense of place which may foster solidarity or stewardship (Dewey *et al.*, 2011). Inspirational values include things such as cultural festivals or works of art. Fish and shellfish species are often considered an important component of the cultural heritage in many coastal communities. Many communities have a long history of fish culture, often chronicled in the names of streets or points of interest, sometimes memorialized in small cultural museums. Many communities also pride themselves on local seafood specialties and their tourist industry is often predicated on the local seafood and customs that are associated with the food. We associate blue crabs with Baltimore, gumbo with New Orleans and bay scallops with Cape Cod. In several communities shellfish farmers have taken the lead on water quality initiatives building community involvement in local stewardship initiatives (Dewey *et al.*, 2011). Putting a dollar value on cultural heritage and an ethic of stewardship is challenging, but not impossible. It would probably involve a contingent valuation survey. For instance, Leggett and Bockstael (2000) proposed a mechanism to evaluate residential land prices based on water quality parameters.

Scholarly values cover different disciplines of studies and in the context of aquaculture may include things such as teaching stakeholders about septic system maintenance or impacts of pet waste disposal on coastal water quality. Shellfish culture and harvesting also have proven to be effective tools in education, helping communities learn about and mobilize to protect their natural resources. Oyster Gardening activities involving thousands or participants in dozens of states have helped create a legion coastal stewards devoted to improving water quality and restoring coastal waters (Hodges *et al.*, 2008).

a) There are strong cultural and religious aspects of the pectinid shell (in particular *Pecten maximus* and *Pecten jacobeus* in Europe) related to the pilgrim trails to saint Jacob/Jacques in Santiago de Compostella in Spain. In several areas of scallop aquaculture development the activities have promoted more awareness about these cultural and religious aspects.

b) Pragmatic values include things such as recreational harvest or ecotourism. In as much as shellfish filtration removes microscopic particles from coastal waters on large scales, we can predict and model the impacts of that filtration on bacterial populations, viral counts and turbidity or water clarity. Contingent valuation studies asked survey respondents their willingness to pay for water suitable for swimming or shellfishing in Chesapeake Bay (Bockstael *et al.*, 1989) and in Narragansett Bay (Hayes *et al.*, 1992). We know that recreational boaters and fishermen also place high values on water quality. Even those that do not actually participate in coastal recreational opportunities exhibit a willingness to pay for the maintenance or restoration of water quality. In survey after survey these opportunities are valued at hundreds of millions of dollars (Henderson and O'Neil, 2003). Evaluating the role of shellfish in maintaining water quality is something that is often done by advocates of oyster restoration, however documenting measurable impacts on water clarity or bacterial numbers on a basin scale might be challenging. Unless shellfish populations are huge, the impacts on measures of water quality are likely to be undetectable. It is something that is easily modeled, but difficult to actually measure.

Methods for Valuating Services

Increased production value occurs as a result of a change in a resource it is relatively straightforward to apply market prices to obtain a strict measure of economic value. Importantly, one should also capture the indirect value to the local economy generated when farms purchase inputs (culture gear, boats, gasoline, etc.) and by the spending of their employees on various goods and services (often referred to a the economic multiplier (Burrage *et al.*, 1990).

Avoided and/or replacement costs can be a measure of the economic value of environmental goods and services based on the cost of avoiding damages due to lost services, the cost of replacing services or the cost of providing substitute services. This is based on the assumption that if people are willing to pay to replace ecosystem services, then those services have a value equal to what people paid to replace them (Boyd and Banzhaf, 2007). Instead providing a strict measure of economic value, this method can provide useful estimates of the value of these ecosystems or services (UNEP, 2005).

Contingent valuation is a survey-based technique for the valuation of goods and services that do not have a market price because they are rarely bought or sold (UNEP, 2005). Examples might include the cultural significance or the enjoyment value that people obtain from a resource. Contingent valuation is often assessed via a stated preference model (as opposed to a price-based revealed preference model.) Respondents are typically asked how much money they would be willing to pay to maintain the existence of (or be compensated for the loss of) an environmental feature.

Valuation and Payment for Ecosystem Services

Many market-based mechanisms have been established to provide Payments for Ecosystem Services (PES) ranging from public supported restoration, privately funded restoration, cap and trade regulations, to sophisticated water quality trading markets. Dozens of types of incentives have been devised to maintain or improved biodiversity or stem erosion or preserve coastal water quality (Arrow *et al.*, 1993; Bennett *et al.*, 2013; Boyd and Banzhaf, 2007; Brumbaugh and Toropova, 2008; Bullock *et al.*, 2011).

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