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20–23 March

Sopot, Poland

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Executive summary

The ICES Working Group on Marine Shellfish Culture (WGMASC), chaired by Pauline Kamermans, held its tenth meeting in Sopot (Poland) on 20–23 March 2012. It was attended by 10 persons from 9 countries. The formal mandate and objectives of the meeting were to work on seven ToRs and to discuss two manuscripts based on finished ToRs. It was a joint meeting with WGEIM because of a request from SCICOM to discuss a plan for a new EG on Sustainable Aquaculture (ToR f). Subgroups were formed for ToR b (Site selection criteria in molluscan offshore aquaculture), ToR c (Aquaculture transfers between sites/countries - impact on wild stock and ToR d (Effects of climate change on shellfish aquaculture). ToR a (Identify emerging shellfish aquaculture issues and science advisory needs), ToR e (Develop a workplan for new Terms of Reference), ToR f (Collaborate with WGEIM to discuss how to revitalize the issue of sustainability in aquaculture) and ToR g (Collaboration with other EGs in relation to the ICES Science Plan) were addressed in a plenary sessions.

ToR a) The following emerging shellfish issues were identified: the efficiency of shellfish culture in order to extract waste, operational tools to assess carrying capacity and benthic impacts, the effect of ocean acidification on hatchery production of shellfish, certification, and diversification to shellfish new species. (Chapter 3).

ToR b) Several countries have initiated research to evaluate the potential for offshore aquaculture of bivalves. The research is dominated by reviews and desk studies, and few resources are invested in tests in the field. Several bottlenecks for an offshore production are identified including the increased cost of establishment and maintenance of systems. A rethinking of the logistics in relation to processing and transport to the marked may identify solutions that compensate the increased cost. Wind parks may potentially support a production of bivalves.

ToR c) 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, to controls with standardised guidelines. (Chapter 5).

ToR d) Increases in temperature and CO_2 are likely to have significant negative consequences for shellfish aquaculture. There is a high probability that climate change and ocean acidification will continue to have consequences for the biogeographical distribution and productivity of cultured shellfish species. Information gaps in our state of knowledge on climate change and ocean acidification impacts hamper the development of potential solutions to the problems that will be faced by shellfish hatcheries, growers, and harvesters. Further studies are critically needed to determine the range of sensitivities, tolerance and adaptation potential of a wide range of aquaculture species to elevated temperatures and reduced pH in the future oceans ocean and potential synergistic effects (Chapter 6).

ToR e) The following topics for new Terms of Reference were identified: environmental remediation through shellfish culture, acceptance of shellfish culture in Marine Protected Areas, sustainability certification for cultured shellfish, restoration and augmentation of wild and cultured shellfish populations, mitigating the anthropo-

genic, biological and environmental risks to the sustainability of mollusc aquaculture (Chapter 7).

ToR f) No change compared to last year (Chapter 8).

ToR g) Subjects discussed were (i) Setting up a new EG on the topic that will supplant or compliment WGMASC and/or WGEIM, or suggesting a way to revitalize the issue through the existing EGs, (ii) How to involve finfish scientists more in the EG(s) and (iii) Developing a work plan for the new/revitalized EG(s) aiming for a startup meeting during ASC 2012 following the aquaculture sessions. First, a list of country-specific priorities with respect to sustainability in aquaculture was developed. This will be circulated to member nations to gauge their level of concern and knowledge of the identified issues. Second, a table of pros and cons of various management structures was developed and debated. Third, a note was drafted to send to member countries to solicit requests for science advice within the scope of knowledge of the EG(s).

1 Opening of the meeting

The ICES Working Group on Marine Shellfish Culture (WGMASC), chaired by Pauline Kamermans (Netherlands), held its tenth meeting in Sopot (Poland) on 20–23 March 2012 at the Institute of Oceanology of the Polish Academy of Sciences. It was attended by 10 persons from 9 countries (Annex 1). The meeting was held at the same location and during the same days as the ICES Working Group on Environmental Interactions of Mariculture (WGEIM). The meeting was opened at 9:00 am Tuesday 20 March with a welcome by Prof. Janusz Pempkowiak, director of the institute and the host Prof. Roman Wenne giving housekeeping information. The chair thanked the hosts for their hospitality. All participants of WGMASC and WGEIM briefly introduced themselves. Two people that had not attended the WGMASC meeting before were welcomed in the group: Corina Busby from Canada and Heather Moore from Northern Ireland.

The first morning of the meeting was devoted to the plan of SCICOM for a new EG on Sustainable Aquaculture. Erik Olsen (chair of SSGHIE) gave a presentation of the plan which was followed by a discussion with all participants of WGMASC and WGEIM. The discussion was continued on Thursday. In total, a little over one day of the meeting was used to formulate recommendations to SCICOM. This is reported on in Section 8 (ToR f) and Annexes 5 and 6.

The chair gave a brief overview of ICES activities since the last WGMASC meeting. One of the issues, discussed by email before the meeting, concerned a proposal from ICES to introduce multi-annual Terms of Reference (ToR) for Science Expert Groups using a staggered process. The concept of having multi-annual ToRs has the goal to strengthen Science Expert Groups with a reduced level of routine reporting and a more focused, accessible, outcome-driven activity. The response of WGMASC members is summarised below:

Reporting will be improved:

1) We welcome the idea of multi-annual Terms of Reference (ToR) with a reduced level of routine reporting. Specifically to aim for review papers in the prime literature.
2) One of the best means of defending the ongoing work of EGs is to ensure that reports are good and read. We now publish our MS work in science journals but now also report to industry magazines such as 'Fish farmer'. ICES must consider how to disseminate up to date and historic work to the community. It should not simply be up to the groups to drive all aspects of the process, direction and processes should be in place and be transparent to enable publication, whether scientific, guidance to industry, or both. Perhaps more emphasis should go on preparation for publication during active sessions to ensure that the process is efficient.
3) What is the "fate" of our recommendations. A review on that question might be useful. Are our reports largely accessible on bibliographic data bases ? Should not these reports be more concise, less formal...?
4) There are relatively few shellfish aquaculture groups, while the industries amongst countries are under severe pressure from environmental and disease issues and urgently needs support from ICES, so long as we can 'sell our wares' effectively. Ours particularly is directed as an aid to industry and should be proactive and more reflect that aim. We should less concen-

trate on the provision of very large detailed reports which few will read and concentrate on focused work with direction for industry.

Management will be more complicated:

5) This new plan will be detrimental to the "bottom up" approach that has made ICES a success. In particular, it will stifle the ability to quickly address high priority, but recently identified issues. It will also be a barrier to establishing cross-cutting initiatives in which multiple EGs need to collaborate on short notice to answer a specific question (i.e. sorry we can't help you because it is not in our long-term plan).

6) The plan means that the development of each ToR has the same rhythm: year 1 defining the work plan and starting writing, year 2 writing and discussion, year 3 finishing the paper. As it is now, each year we have ToRs in a different phase of development which makes the meeting more dynamic and provides opportunities for members to choose between activities (brainstorming, searching the literature, summarising papers, discussing conclusions, etc).

7) In addition, the new plan means that in the final meeting not only the products need to be finalised and an evaluation and reflection of objectives and goals need to be carried out, but also both a new chair and a new set of ToRs need to be defined. If, for some reason this is not achieved it means the end of the group. Thus, there will be a lot of pressure on the group during that meeting. Because of this, we support the suggestion that requests for extension have to be considered before the end of a term, to avoid uncertainty and provide opportunities for interactions between EGs and SCICOM. Our suggestion would be to have 3-year ToRs, but let them start in different years. We realise that that makes it more difficult to end an EG, but we do believe the meetings and products would benefit from this. It would still be an option to have an evaluation every 3 years with a possible outcome of non-continuation of the group.

Participation may be less:

8) We doubt that some members will stay with a group knowing that their main topic of interest cannot be considered as a ToR for 3 years.

9) In our "molluscs group" specifically, we address wide questions, that need a large area of expertise (from generalists). We are not sure that our limited group has time to circumvent all aspects of some complex questions within 1 week per year (climate change...). So there is a risk not to master entirely the field of knowledge required. Less subjects, treated during 3 years, may diminish that risk (also let us confront our proposals to more of our expert-colleagues, during intersessions). For the same reason, it may be wishable to renew, at least partly, our group of experts according to the new 3 years-ToRs?

10) In the proposal to introduce multi-annual Terms of Reference, under Annex 4 add an additional point to justify inclusion in the group. Those not attending/contributing within the last 3 years. Groups should be dynamic, fresh and capable of meeting new challenges. Should those not attending, be approached as to their commitment to ICES? It is difficult enough generating and maintaining EGs, including ensuring attendance at meetings. Disbanding, unless justification is provided, after 3 years, may not be the way to go as you could lose a valuable resource in professionals and their

time – funding for which is provided externally to ICES. The biggest challenge to ICES we perceive here is justifying time and money when the results of ICES work, although invaluable reports, is not really 'out there' such to justify the expense.

The presence of Erik Olsen provided the opportunity to briefly discuss this further before the SCICOM meeting 26 March. Based on his replies there seems to be room for flexibility regarding our points 5, 6 and 7.

The chair gave an update on the status of the two manuscripts that are in preparation on Terms of Reference that were closed in earlier years:

- Peter J. Cranford, Pauline Kamermans, Gesche Krause, Joseph Mazurié, Bela Buck, Per Dolmer, David Fraser, Michael Gubbins, Kris Van Nieuwenhove, Adoración Sanchez-Mata, and Øivind Strand. An Ecosystem-Based Approach and Management Framework for the Integrated Evaluation of Bivalve Aquaculture Impacts. **Accepted** by Aquaculture Environment Interactions.
- D. Fraser, M. Brenner, F. Muehlbauer, M. Gubbins, K. Van Nieuwenhove, B. H. Buck, O. Strand, J. Mazurié, G. Thorarinsdottir, P. Dolmer, F. O`Beirn, A. Sanchez-Mata, P. Kamermans. Bivalve Aquaculture Transfers in Atlantic Europe Rejected by Aqua-culture International. To be submitted to a new journal.

During the meeting participants provided comments the Bivalve Aquaculture Transfers manuscript to Matthias Brenner. The comments will be included in the new version that is presently prepared and will be re-submitted soon. It was decided to split the paper by Fraser *et al.* into two parts (D. Fraser, M. Brenner, F. Muehlbauer, M. Gubbins, K. Van Nieuwenhove, B. H. Buck, O. Strand, J. Mazurié, G. Thorarinsdottir, P. Dolmer, F. O`Beirn, A. Sanchez-Mata, P. Kamermans. Bivalve Aquaculture Transfers in Atlantic Europe Part I: transfer activities and legal background and M. Brenner, D. Fraser, K. Van Nieuwenhove, F. O`Beirn, M. Gubbins, B. H. Buck, J. Mazurié, G. Thorarinsdottir, P. Dolmer, A. Sanchez-Mata, O. Strand, P. Kamermans. Bivalve Aquaculture Transfers in Atlantic Europe Part II: environmental impacts).

2 Adoption of the agenda

The agenda (Annex 2) was formally accepted. The WGMASC decided to continue the past practice of addressing most ToRs separately within subgroups, followed by plenary sessions where subgroup activities are discussed by the full WGMASC and the draft report is formally accepted. Subgroup leaders appointed by the WGMASC chair act as rapporteur for preparing draft reports from the work of subgroups and report on their groups activities during plenary sessions. One new item was added to the agenda: a presentation by Peter Cranford on IMTA research in Canada.

A general discussion on plans for each WGMASC Terms of Reference was held. Al main terms of reference (ToR b, ToR c, ToR d) were in their final year. The subgroup leader for ToR b (Site selection criteria in molluscan aquaculture) was Bela Buck and other participants were Per Dolmer and Corina Busby. Finishing ToR c (Aquaculture transfers between sites/countries - impact on wild stock) was taken up by Helen Moore with help of Francis O'Beirn and Roman Wenne. Subgroup leader for ToR d (Effects of climate change on shellfish aquaculture) was Peter Cranford with participation Oivind Strand and Joseph Marzurie. As in other years it was decided to address ToR a (Identify emerging shellfish aquaculture issues and science advisory needs) and ToR g (Collaboration with other EGs in relation to the ICES Science Plan) in a plenary session with the chair as rapporteur.

3 Identify emerging shellfish aquaculture issues and related science advisory needs for maintaining the sustainability of living marine resources and the protection of the marine environment (ToR a)

A brainstorm during the meeting yielded the following list of emerging shellfish issues:

- The efficiency of shellfish culture in order to extract waste (nutrients, organic matter, and contaminants) needs to be studied in more detail to understand as well as recommend extractive species for bio-remediation. E.g. what fraction of the nutrients is retained by deposition of shellfish feces? The impact of mitigation measure should have an ecosystem perspective. E.g. what is the effect of harvesting shellfish before they spawn?
- Regulators feel there is a lack of operational tools to assess carrying capacity and benthic impacts. What indicators and thresholds can be used? This highlights the need for dissemination the work we have done on this subject, e.g. through the publication of Cranford *et al.* An Ecosystem-Based Approach and Management Framework for the Integrated Evaluation of Bivalve Aquaculture Impacts. Accepted by Aquaculture Environment Interactions.
- The effect of ocean acidification on hatchery production of shellfish.
- For Europe, implementation of regulations such as Natura 2000, the Marine Strategy Framework Directive and the Water Framework Directive seems to differ among countries. What are the criteria used? What to do when there are no baselines?
- Certification or labellism is gaining popularity. E.g. you have the Marine Stewardship Council, Aquaculture Stewardship Council, organic aquaculture, Label Rouge that indicates where the product comes from. To be able to judge the quality of the different labels WGMASC could recommend on comprehensiveness. What criteria, indicators and thresholds are used? What mode of certification is necessary that the consumer is able to understand and follow?
- Diversification to shellfish new species.

4 Review the state of the knowledge on site selection criteria in molluscan aquaculture with particular reference to accessing and developing offshore facilities (ToR b)

4.1 Background

Spatial competition for aquaculture sites along coastal seas has encouraged the initiative of moving shellfish aquaculture into the open ocean at exposed sites, particularly within the European Economic Zone. These offshore sites require an understanding of the adaptive capabilities and limitations in growth potential for species at these sites, the development of new technologies capable of withstanding these high energy environments and the necessary institutional arrangements (e.g. marine spatial planning). It is also essential in site selection to consider biotic and abiotic factors in association with economic, ecological and socio-economic perspectives, whether in the coastal zone or at offshore locations. Beside basic investigations on these parameters, conditions of a preferred site can be investigated by analyzing the overall health status, growth and survival performance of shellfish grown in different areas (e.g. blue mussels) as a bio-indicator of site suitability. This ToR aims to: assess site selection criteria in ICES countries; provide an overview of current research and commercial operations of offshore shellfish farming, both for spat collection and for on-growing to market size. In addition, it is intended to investigate the sustainable use of oceans by integrating aquaculture and fisheries and assess the potential for combining shellfish culture with other offshore constructions such as renewable energy facilities or any other.

ToR b) "Review the state of the knowledge of site selection criteria in molluscan aquaculture with particular reference to accessing and developing offshore facilities" is a very complex subject and was the first time discussed in the WGMASC at the annual meeting in Galway (IRL) 2010. During the meeting and the ongoing work on this ToR we decided to present an introduction into "Offshore Shellfish Cultivation". Further, an overview on the current status of offshore shellfish cultivation will be presented.

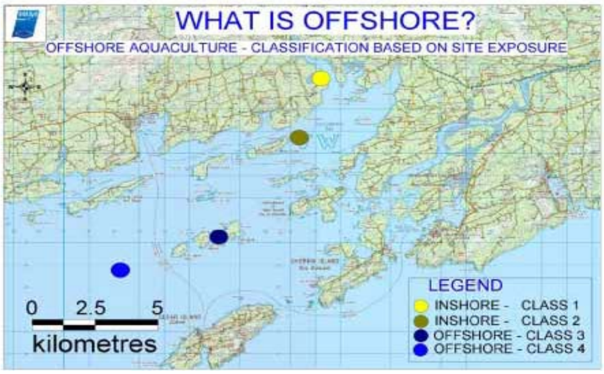
4.2 Workplan

In the first year (2010) the topic of site-selection criteria with particular reference to offshore areas was defined. Further, the state of the art of offshore shellfish culture and the various intentions to move off the coast into high energy environments in ICES countries was reviewed. In addition, biological, technical, and economic records were reviewed with special focus on site-selection. In the following year (2011), the collection and collation of data continued, especially for ecological site-selection criteria and an update on country-specific information was conducted. This year, (2012), after three years of work, ToR b) will be completed with a final report including marine spatial planning, recommendations on scientific tools for decision support and shellfish culture in offshore areas in general. The complete 3 years' work will be summarized in a publication in an appropriate peer-reviewed journal within 2012.

4.3 Definition of the term "offshore aquaculture (OA)"

Offshore aquaculture (OA), also described as open ocean aquaculture (OOA), refers to culture operations ongoing in frequently hostile open ocean environments. There are various definitions on what can be considered as "real" offshore aquaculture. In the implementation of strategies of marine spatial planning within EU member states, as well as in the development of internationally operating industries off the coast, such as the extraction of gas and oil and the massive construction of offshore wind turbines, "offshore" is declared as being a site which is beyond the twelve nautical mile zone of the coastal sea. However, for any aquaculture enterprise "offshore" is defined as being a marine environment fully exposed to a wide range of oceanographic conditions (Ryan 2004), such as strong currents, swell and/or high waves. This increased exposure to higher wave energy is often linked to distance from shore or lack of shelter by topographical features such as islands or headlands that can mitigate the force of ocean and wind-generated waves. Following Buck (2004, 2007b), offshore sites are at least eight nautical miles off the coast to avoid tremendous stakeholder conflicts in nearer coastal areas (Dahle *et al.* 1991). However, exposed sites are also existent in nearshore areas. Therefore, the term "offshore" should be defined specifically on a case to case basis. Figure 4.1 can help to classify which certain sites may be described as "offshore".

The classification scheme of the Norwegian government for offshore fish farms is based on significant wave heights (Table 4.1) and does not include factors such as wave period or current speed. Therefore, this classification is less desirable for use in site-selection for offshore shellfish cultivation.



Class	1	2	3	4
Conventional Description (In relation to site exposure)	Sheltered Inshore Site	Semi-Exposed Inshore Site	Exposed Offshore Site	Open Ocean Offshore Site

Figure 4.1. Site classification as a definition for the term "offshore" (modified after Ryan 2004).

Table 4.1. Norwegian aquaculture site classification scheme (modified after Ryan 2004).

Site Class	Significant Wave Height [m]	Degree of Exposure
1	< 0.5	Small
2	0.5–1.0	Moderate
3	1.0–2.0	Medium
4	2.0–3.0	High
5	> 3.0	extreme

4.4 Summary of the reasons to move offshore

The development of "offshore aquaculture" or "open ocean aquaculture" has often been described as the "Blue Revolution", which puts aquaculture development on the same scale as the advances made in agriculture during the so-called "Green Revolution". A shortage of marine proteins due to commercial fisheries having reached capacity while demand continues to increase, will, in the longer-term support a significant expansion of aquaculture of bivalve shellfish. The rationale for the emergence of scientific considerations and semi-commercial trials to develop aquaculture operations off the coast is quite diverse. Expansion of bivalve aquaculture, land-based and/or nearshore, is limited for various reasons, such as political, environmental, economic, technical and resource constraints. With the exception of hatchery and nursery production, the space and volume of phytoplankton required to grow market-size bivalve shellfish in land-based systems is enormous, and therefore not yet economically viable (Cheney *et al.* 2010). Space for the expansion of bivalve cultivation enterprises is mainly the limiting factor a farmer has to cope with due to competition with a variety of other marine coastal stakeholders, commercial or recreational based. Table 4.2 gives an overview of the main drivers for the development of offshore aquaculture.

Table 4.2. Overview of the main reasons for the development of offshore shellfish aquaculture.

No.	Group	Reason to move off the coast
1	space/ acceptance	trends towards larger production unit sizes and lack of in-shore sites for aquaculture expansion and/or development (especially in countries where capital for aquaculture development is available)
		perceived constraints on carrying capacity and increasing pressures on coastal habitats from many resource users, making site acquisition for mariculture development increasingly difficult
		in some regions there may be reduced conflicts with other user groups (such as shipping [trade or private], recreational activities, extraction or disposal of gravel, marine missions, fisheries, mariculture, offshore wind farms, cable and pipelines, establishment of nature reserves and other marine and coastal protected areas) and therefore better acceptance among stakeholder groups
		potential multi- or co-use of sites or installations with other stakeholders
2	water quality/ impact on ecosystem	higher exchange of oxygen
		lower exposure to human sources of pollution (e.g. urban sewage) and therefore access to cleaner water
		more consistent temperature due to larger water body (less stress on cultured animals)
		higher mixing, availability and renewal of phytoplankton
		moving offshore could potentially reduce disease and improve candidate performance as well as prevent the culture candidates of being infested by some of the typical macro-parasites (e.g. polychates, copepods, tremetodes)
		the potential to reduce some of the negative environmental impacts of coastal shellfish farming, and optimize environmental conditions for various marine species through larger carrying and assimilative capacities
3	demand/ production	world demand for seafood increases annually by 2.2 million metric tons per year in order to maintain the current consumption level of 29 kilograms of seafood per person per year (Worldbank, 2010), representing a 40% increase to approximately 180 million tonnes by the year 2030.
		The development of offshore aquaculture can lead to an increase in production and could therefore be a part of the solution to fulfilling this demand
4	equipment/ techniques/ design	operating and infrastructure costs (vessels, land-based facilities) as well as the infrastructure support systems are not necessarily higher in total costs but will be discussed specifically (see Table 4.4 in Section 4.5.4)

		offshore systems can be constructed differently than installations in nearshore environments (more space and therefore larger farm potential, deeper water allows submergible designs => less conflicts with shipping operations and other stakeholders)
		potential to connect aquaculture installations with existing offshore infrastructure (e.g. oil and gas platforms, renewable energy units [offshore wind farms, current or tidal plants], floating devices, control installations)
5	co-use with existing offshore installations	see item 4 above
		high cost infrastructure (e.g., boats, cranes) for regular servicing of sites may be shared by multiple enterprises
		options to link individual activities of various offshore installations (for instance, charter contracts for specially-designed mussel harvesting vessels could be aimed as a solution for transporting personnel (e.g., wind farm technicians) to offshore locations at times of planned, preventive, operation and maintenance activities)
		placement of mariculture structures in defined corridors between, e.g. within wind farm turbines reduces the spatial need through multiple use of ocean territories
		training in various field can be conducted in joint study programme
		saving time and costs for conducting a joint environmental impact assessment as well as other permitting procedures
6	Miscellaneous	seabed topography offshore (with an increasing distance from the shore) generally changes into deeper water environments which allows the submersion of equipment, thus reducing the drag and load (due to wave action) on the entire system
		submergible systems allow overstay during severe winter periods thereby saving money by not having to remove and replace infrastructure
		In some regions, offshore shellfish aquaculture can provide a new product to the market. This new product can support other sectors such as tourism (tourists come to the Belgian village Nieuwpoort to eat the Belgian mussels), fish auctions (Belgian mussels are an important new product for the Nieuwpoort fish auction)

4.5 Current stage of OA in ICES countries and beyond

4.5.1 Conferences and feasibility studies on offshore aquaculture with special focus on shellfish cultivation

A number of international meetings regarding offshore aquaculture have taken place in recent years. In 1997 and in 2004 the International Centre for Advanced Mediterranean Agronomic Studies (CIHEAM) organised workshops on Mediterranean Offshore Aquaculture at the Mediterranean Agronomic Institute of Zaragoza (IAMZ) in Zaragoza (Spain) (Muir & Basurco 2000). In 1998, the Faculty of Mediterranean Engineering in Haifa (Israel) ran a workshop entitled Offshore Technologies for Aquaculture (Biran 1999). The best-known meetings on offshore aquaculture were probably the four international conferences on Open Ocean Aquaculture held in Maine (US) in 1996 (Polk 1996), in Hawaii (US) in 1997 (Helsley 1998), in Texas (US) in 1998 (Stickney 1999) and in New Brunswick (Canada) in 2001 (Bridger & Costa-Pierce 2003). The US Sea Grant Programme was the main sponsor of the first three events, and the World Aquaculture Society ran the fourth conference. In 2009, a conference also sponsored by Sea Grant and German Research Institutions on "The Ecology of Marine Wind Farms: Perspectives on Impact Mitigation, Siting, and Future Uses" was held in Rhode Island (US) with a main focus on shellfish farming (Costa-Pierce 2009). In Europe, similar conferences were organized by various institutes and universities. In Germany, two workshops were held regarding the combination of offshore facilities with offshore aquaculture in Emmelsbüll-Horsbüll in 2003 (Ewaldsen 2003) and in Bremerhaven in 2004 (Michler 2004), respectively. In the Netherlands three workshops took place on similar aspects in Amsterdam in 2003 (Emmelkamp 2003) and 2006 (van Beek *et al.* 2008) as well as in Den Haag in 2007. In London (UK) a stakeholder meeting was organised in 2005 for the suitability of offshore aquaculture in existing offshore structures (Mee & Kavalam 2006) and in Ireland a conference on "Farming the Deep Blue" was held in 2004 (Ryan 2004). Finally, a series of biennial conferences called "Offshore Mariculture" were held in St. George's Bay (Malta) in 2006, in Alicante (Spain) in 2008, in Dubrovnik (Croatia) in 2010 and will take place in Izmir (Turkey) in late 2012. Some workshops in 2010 and 2011 included or even focused on offshore aquaculture such as the Kiel Institute for World Economy with international experts in aquaculture in Kiel (Germany), the DTU-Aqua "Perspectives for sea based production of food – The blue revolution" in Copenhagen (Denmark), the Ministry of Economic Affairs Agriculture and Innovation of the Netherlands "Offshore Mussel farming in the North Sea" in The Haque (The Netherlands) as well as the North Sea Marine Cluster (NSMC) "Marine Protected Areas: Making them happen" in London (UK) in 2011. Other meetings and conferences organised by the Institute for Marine Resources (IMARE) was the "Marine Resources and Beyond 2011" conference in Bremerhaven (Germany) or the Stakeholder Workshop on the combination of offshore wind and aquaculture in Ostend (Belgium) organized by eCOAST in 2011, respectively. In 2012 offshore mussel farming was also presented on the North Atlantic Seafood Forum (NASF) conference in Oslo (Norway). Finally, the Aquaculture Forum on "Open Ocean Aquaculture Development: From Visions to Reality, the Future of Offshore Farming" was an important step not only for presenting the state of the art science but also for passing the "Bremerhaven Declaration" for the future of global open ocean aquaculture (see appendix A). Most conferences and workshops presented the current research in proceedings.

Further publications on the feasibility of offshore aquaculture were published regarding aquaculture enterprises in the German North Sea by Buck (2002, 2007a), Michler-Cieluch (2009), Brenner (2009) and Pogoda (2012). For the Belgium Atlantic Coast Delbare (2001), MUMM (2005) and Van Nieuwenhove (2008) published reports on offshore aquaculture, for the Netherlands studies that explore possibilities for mussel culture were reported by Steenbergen *et al.* (2005) and Kamermans *et al.* (2011) and for the French coast a report has also been published (Mille 2010). Finally, in Denmark a report by Christensen *et al.* (2009) was written concerning the potential for production of mussels associated with wind farms in the Baltic Sea.

4.5.2 Experiences in ICES member countries

<u>France:</u> In France, commercial offshore mussel farming is taking place in three areas: in the Mediterranean Sea, on the Atlantic coast and in the North Sea.

In the Mediterranean, offshore mussel farming is taking place in four locations (Séte/Marseillan, les Aresquiers, Vendres and Gruissan, Figure 4.2) on a total surface of 4500 ha. The main species farmed is *Mytillus galloprovincialis* although experiments with oysters (both *O. edulis* and *C. gigas*) have been done. The mussels are farmed on submerged longlines (Danioux *et al.*, 2000). In 1995 the production of offshore mussels dramatically decreased because of predation by sea bream (*Sparus auratus*). In 1995, 10 000 tons of mussels were harvested; in 2004, 4000 tons. In 2008 a licence was granted for 1190 longlines with a length of 250m each (Kamermans *et al.*, 2011).

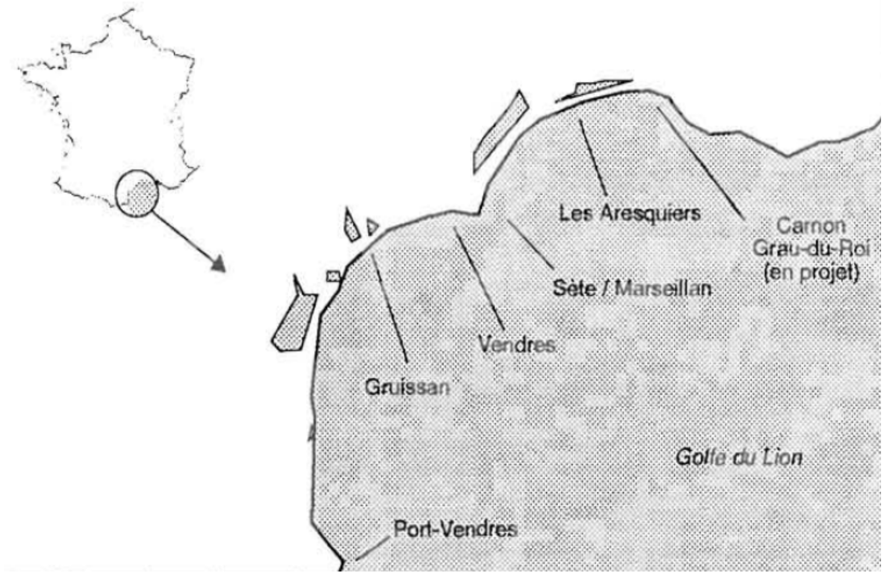


Figure 4.2. Location of the French offshore mussel cultures in the Mediterranean (source: Bompais, 1991).

On the Atlantic coast near Pertuis-Breton, longlines and other constructions for spat collection and grow-out have been developed. Some of the ropes are used for spat collection, as a complement to intertidal spat collection (which may sometimes be insufficient, for instance during cold, dry winters). Many ropes are used for production of "half-mussels", before transfer to intertidal bouchots (Kamermans *et al.*, 2011). The lines used called "subfloating lines" (Danioux *et al.*, 2000) differ from the Mediterranean longlines in that they are nearer to the surface (minus 1 m approximately) and they have no "legs" except at the extremities.

In Brittany, several projects have existed, during the past 20 years, but only a few are still in operation (individual projects instead of a collective as in Mediterranean and Pertuis Breton).

In the North of France, 5 to 7 km off the coast of Zuydcoote (Nord-Pas-de-Calais), a cooperation is growing the "Moules de Dunkerque" or the "Moules des Bancs de Flandre". The farmers are using a specific type of longline with heavy anchors and ropes designed to withstand the rough North Sea conditions. The system is working fine and farmers are harvesting about 600 tonnes a year (based on press articles).

Recently a review of the French situation of shellfish culture in "deep water" (concerning deep water and offshore farming) was presented at the Aglia conference in Nantes, France (Mille, 2010).

<u>Germany:</u> In Germany, no commercial offshore farm exists yet. The commercial mussel cultivation in Germany is based on an extensive on-bottom culture (Seaman &

Ruth 1997) and depends entirely on natural resources for food, spat and space. Other techniques such as suspended designs (e.g. longlines, longtubes) do exist. Commercial oyster farming is carried out on a small scale in the nearshore (Buck *et al.* 2006). Nevertheless, due to stakeholder conflicts (e.g. Buck *et al.* 2004) and a lack of spat availability (Walter & Liebezeit 2003), mussel farmers will need to move offshore where space will not be the determining factor, adequate settlement of spat is more likely. Various projects are underway to test the feasibility of offshore farming in the EEZ of the German Bight.

Newcomers – the offshore wind farmers – are covering large areas in the German North and Baltic Sea which may provide the opportunity to use these areas in a multifunctional way by incorporating aquaculture (e.g. mussel, oyster and seaweed cultivation) within the wind farm sites. To date all attempts to move bivalve aquaculture off the coast to a more hostile environment within wind farm areas are on a pilot scale. Various projects including scientific studies on the biology, techniques and system design, economic potential, ICZM, and the regulatory framework as well as potential synergy with offshore wind turbines have been investigated (see Figure 4.3; for review see e.g. Buck 2004; Buck *et al.* 2008; Michler-Cieluch 2009; Brenner 2009; Pogoda 2012).

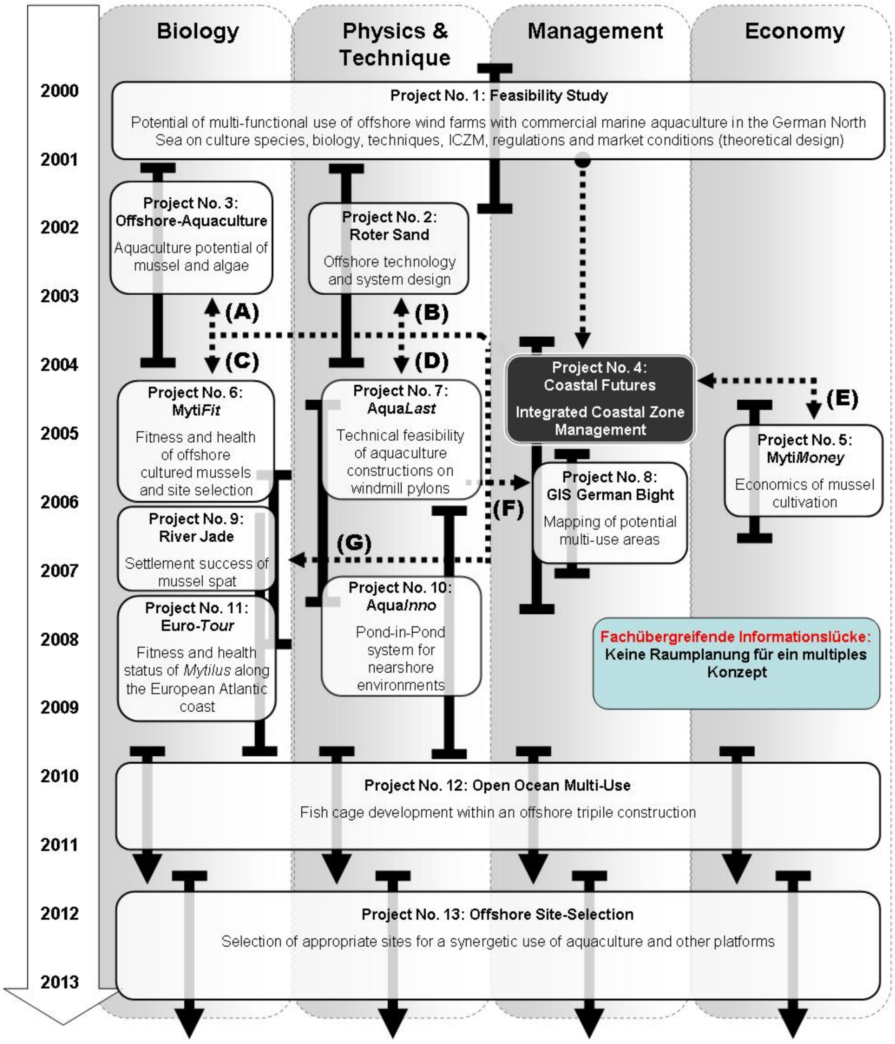


Figure 4.3. Chronological order of completed and ongoing research projects dealing with the combination of offshore wind farming and open ocean aquaculture (modified after Buck *et al.* 2008).

Iceland: In Iceland there have been no attempts yet to move shellfish operations off the coast and into the open ocean.

Spain: In Spain there have been no attempts yet to move shellfish operations off the coast into the open ocean. The only test site off the coast of Santander, where attempts to install an offshore resistant longline for mussel cultivation took place, failed due to economic reasons.

Belgium: As the Belgian part of the North Sea is used intensively by dredging, military, shipping, wind farm and fisheries activities almost no space is left for offshore mariculture. Therefore, the 4 mussel areas (Figure 4.4) that were appointed by the "Ministerieel Besluit" (Ministerial Decree) MB 97/16166 were identified because they were not suitable for other activities. The area D1 is situated near a shipwreck, the areas of Oostdyck and Westhinder are located in the proximity of a measurement or radar pole and the area "open achter de Thorntonbank" (on and behind the Thorntonbank) is appointed as an area for wind farms.

The area D1 is located 10 km from the harbor of Nieuwpoort and, as it is the area closest to the coast, it is preferred by the farmers. This area has the disadvantage of having a depth of only eight meters, which makes the use of submerged longlines difficult. This situation has forced the farmers to find alternative technologies such as buoys and cages to support their culture operations. More recently the farmers have started using submerged longlines in the area.

The area Oostdyck is located 25 km from the harbor of Nieuwpoort and is even shallower than the D1 area (only 7 m). The area is located on top of a sandbank and is therefore exposed to breaking waves as on a beach. The area is characterized by a low spatfall and slow mussel growth (Van Nieuwenhove 2008) and has only been used for experimental trials.

The Westhinder area is a little deeper (11 m) and farmers have tried to use submerged longlines in this area. The area is located 32 km from the harbor of Nieuwpoort and has only been used for experimental trials.

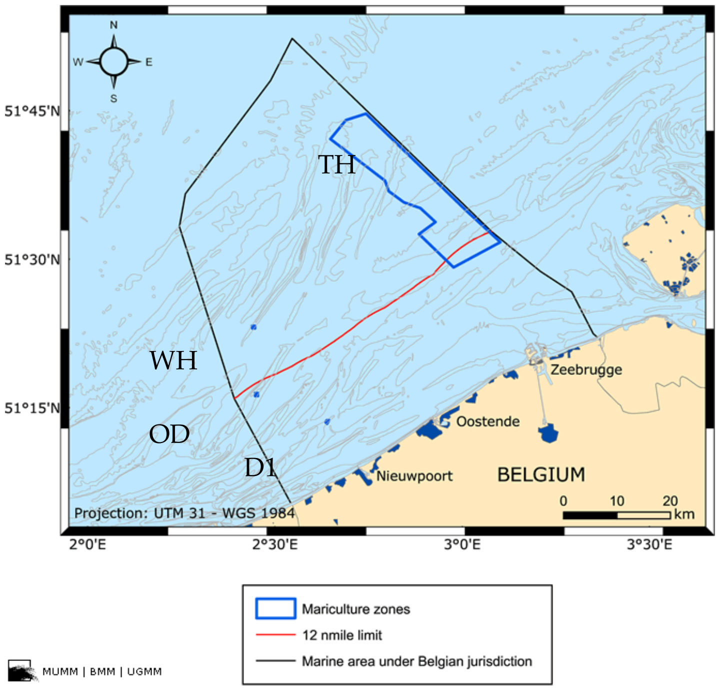


Figure 4.4. Location of the designated Belgian mussel areas D1, Oostdyck (OD), Westhinder (WH) and Thorntonbank (TH) (source: www.mumm.ac.be).

The Thorntonbank area is a large area with a depth ranging from 12 to 30m and is located 24 to 58 km from the harbor of Zeebrugge. As this area is also appointed as wind farm area there may be an opportunity to combine offshore shellfish farming with wind farms. However, Belgian policy makers are convinced that it is unsafe to allow shipping traffic in a wind farm area and it will be completely forbidden by the new "Koninklijk Besluit" (Royal Decree). The Institute for Agricultural and Fisheries Research (ILVO) is currently working on a desk study to combine wind farms, passive fishing and aquaculture. This study might help the policy makers and wind farm concession owners to allow aquaculture in this area.

Canada: Canada has some experience in offshore aquaculture and hosted the fourth conference on Open Ocean Aquaculture (see above). Offshore aquaculture development is seen as a viable option for expansion of the Canadian shellfish aquaculture industry and it has been endorsed by the National Aquaculture Strategic Plan Initiative (NASAPI).

At the present time there are no offshore aquaculture facilities on the west coast of Canada but there are several initiatives ongoing on the on the east coast, which are at various stages of development.

In the Baie des Chaleurs region of Quebec, there are several producers that are growing mussels (*Mytilus edulis*) in offshore sites on self-operating collectors or autocollectors where mussel seed is collected and grown without socking (Bilodeau *et al.* 2008).

The further development of shellfish aquaculture in the Gulf of St. Lawrence Region in Canada is currently restricted by access to suitable sites. Many shellfish aquaculturists are looking towards expanding or moving offshore should leases become available, however, the process of granting offshore sites can be very lengthy (> four years). This is in part because managers have very little information about the environmental ecosystem and far-field indicators for the potential offshore sites. A recent project was funded by DFO to develop marine bottom maps for the Gulf of St. Lawrence Region. This will help farmers identify sites for offshore aquaculture and enable regulators make decisions regarding potential environmental impacts of offshore culture (PARR Project G-2009-PARR-03).

In New Brunswick there is interest in developing offshore Giant Scallop (*Placopecten magellanicus*) culture in association with ongoing exposed site mussel culture. The industry association Pecten UPM/MFU Inc. has completed a study that investigated the feasibility of culturing Giant Scallop at an exposed location in Baie des Chaleurs and in the Northumberland Strait. During the second and third years of suspension culture trials, high mortalities (about 50%) were observed (Nowlan *et al.*, 2011). A project (ACRDP Project MG-10-02-002) is currently underway to examine various culture gears and husbandry methods to help improve survival in exposed locations. There are also activities ongoing toward development of techniques that will allow the growth of Eastern Oyster (*Crassostrea virginica*) at more exposed locations (See Section 4.5.4).

<u>The Netherlands:</u> In the Netherlands no offshore farms are present but they show a lot of interest in offshore shellfish farming as an alternative to inshore spat collection. Examples of this interest are the development of various offshore constructions such as the "Mosseldobber" and the construction developed by Gafmar Seafood. A desk study and sampling of buoys of shipping lanes was carried out to study possibilities for off-shore mussel farming. This yielded a report which included a map with potentially suitable areas (Steenbergen *et al.*, 2005). More recently, 2 reports were made by TNO and IMARES for the Ministery of Agriculture, Nature and Food Quality (Reijs *et al.*, 2008) and the Ministry of Economic affairs, Agriculture and Innovation (Kamermans *et al.*, 2011). In 2012 the government has opened a call for off-shore mussel farming experiments. This has yielded five proposals.

<u>Denmark:</u> The Danish Government agreed on a development plan in 2006 and 2009 that supports a significant growth in mariculture. Increased production of fish will, in the future, be located in exposed sites in order to reduce impact on ecosystems, and furthermore nutrients will be extracted by combining fish production and production of compensation cultures extraction nutrients. The Danish Aquaculture Association has identified offshore production as a solution in conflicts with an increased production and its correlation with the ongoing competition for areas at sea. Two pilot projects are initiated. The first evaluates the potential for use of offshore wind farms for shellfish aquaculture and the second project is conducting a general evaluation of the potential for offshore aquaculture in Danish waters. In 2011 a R&D project was initiated, aiming to develop and test offshore aquaculture, including finfish and Blue

Mussels. All projects are conducted in cooperation between industry and research institutions.

Ireland: In Ireland various tests were done with semi-submerged and submerged longlines and the Smart Farm system in exposed sites at the south-west coast. Results from the experiments where disappointing. The Smart Farm system failed in all test locations and the harvesting machine could never be operated to its full potential. The semi-submerged longlines are the most successful to date, but for a successful harvest and management a dedicated, purpose built workboat is essential (Daly, 2007).

USA: In 1998, the University of New Hampshire initiated the Open Ocean Aquaculture Demonstration Project to investigate the commercial potential of environmental responsible seafood production, employment opportunities, engineering solutions and operational methodologies of offshore aquaculture (Bucklin & Howell 1998). As part of the project Langan & Horton (2003) deployed two 120 m submerged longlines for shellfish culture 10 km off the coast of Portsmouth (New Hampshire) in the south western Gulf of Maine, where the biological and commercial feasibility of *Mytilus edulis* cultivation were tested. Some test trials were conducted in the vicinity of Block Island off the coast of Rhode Island where offshore wind turbines are planned in a traditional mussel spat collecting area. Similar plans exist for the area around *Cape Wind*, a nearshore wind farm off Woods Hole (MA).

UK: In the UK John Holmyard of Offshore Shellfish Ltd. obtained a licence for a pilot study on offshore mussel farming in Lyme Bay (Devon). The final goal is to develop a 15.4 km^2 offshore mussel farm. The farm, where the mussels are grown on longlines, will be able to produce 10 000 tonnes of mussels a year (Kamermans, 2011).

Norway: In Norway there have been no attempts yet to move shellfish operations off the coast into the open ocean.

Sweden: In Sweden there have been no attempts yet to move shellfish operations off the coast into the open ocean.

Portugal: I Portugal there are two offshore aquaculture facilities for shellfish production (mussels and oysters) located at sites close to land (> 1 nm) with a significant wave heights of 3–5 m.

4.5.3 Candidates and Biological Research on OA

Several species have been identified as candidates that can be farmed successfully in offshore hostile environments. Cheney *et al.* (2010) listed bivalve species which would be suitable (Table 4.3). Biological based investigations to identify suitable candidates include consideration of growth performance, larval abundance, settlement, resistance to harsh conditions, and the health and fitness of bivalve candidates. Most experiments and work to date have focused primarily on several mussel species and, to a lesser extent, on scallops and oysters. Mussels are the preferred organisms to be cultured because they are native species in most parts of the northern hemisphere and attach tightly to structure in the water with a "byssus". Furthermore, they are hardy, readily seed themselves in the wild and are available year-round (Seed & Suchanek 1992; Gosling 2003; Buck *et al.* 2010).

Mussels cultivated in offshore areas, for the most part, show high growth rates compared to those grown in nearshore sites (e.g. Buck 2004; Buck 2007b). This is due to the fact that water quality (e.g. urban sewage) and oxygen concentrations are more suitable and the infestation of parasites is low or non-existent. In areas under estuarine influence exposure to fluvial transport points to a comparable probability for high contamination loads similar to nearshore areas could reduce fitness (Brenner *et al.* 2012). Larval abundance tends to decrease with increasing distance from shore (Walter *et al.* 2001), but at some offshore sites it is still sufficient enough to facilitate adequate seeding (Buck 2007). Alternatively, the absence of spat availability may be viewed as an advantage (no fouling, only one year-class). The benefit for a low settlement can lead to a one-step cultivation technique (no thinning procedure) if collecting and grow-out sites are similar. The lower settlement success on one hand results in a limited commercial potential, but on the other hand eases handling and maintenance. However, Belgian experiments have shown a massive settlement making thinning essential (Van Nieuwenhove 2008). In areas with low settlement success we would, without the calculation of the economic potential at a certain site recommend to collect the spat traditionally in nearshore areas and then transfer it to the offshore site (Christensen 2008). In Brittany, local offshore spat contains hybrids of *M. edulis* and *M. galloprovincialis*. The hybrid mussels have the advantage of better byssal attachment, but have a lower commercial value (Bierne *et al.* 2002).

Oysters (*C. gigas*, *O. edulis*) grow well at exposed sites (Pogoda *et al.* 2011), and have a suitable fitness (Pogoda *et al.* in press). However, growth rates do not exceed known rates from nearshore environments. Similar to offshore cultivated mussels, oysters grown offshore show no infestations by macro-parasites (Pogoda *et al.* 2012).

The resistance of mussels to strong currents as well as high waves and swell depends on the degree and duration of these forces and also on the species (*M. galloprovincialis* is more resistant than *M. edulis*). Information on the hydrodynamic conditions is important due to the fact that e.g. mussels and oysters do adapt to harsh conditions but do not automatically grow fast. Even when flow rates are increasing and consequently bring more food, which stimulates mussels and oysters to feed intensively, at a certain current velocity growth is reduced due to a pressure differential between inhalant and exhalent siphons (Wildish & Kristmanson (1988, Rosenberg and Loo 1983). Further, exposure to high waves/swell also could reduce production rates due to the loss of mussels through detachment (Scarratt 1993). Oyster mortality occurred when exposed to extreme wave action due to shell abrasion (Pogoda 2012). Even if mussels cultivated in a high energy environment could sooner or later adapt to the permanent physical stress by increasing the strength and number of byssal thread attachments system design adapted from sheltered environmnets, such as collector devices, have to modified to prevent detachment (Brenner & Buck 2010).

In nearshore intertidal areas, mussels are potentially exposed to high concentrations of pollutants, pesticides, estuarine runoff etc., which can pose a threat to consumer health. The scope of growth, i.e. the energy available for growth, of an organism is usually directly and positively correlated to their overall health condition (Allen & Moore 2004). But organisms with high growth rates and a healthy appearance are no guarantee of a healthy food product for human consumption. For example, in waters eutrophicated by urban sewage, mussels show good growth performance but the microbial status of these mussels would most likely exclude them from consumption, since they may carry various human pathogens. Even in developed countries with strict legislation for the treatment of wastewater, mussels can function as carriers of serious microbial agents. This risk should be reduced with offshore cultivated mussels, where the environment is cleaner due to dilution of contaminants.

All known micro- and macro-parasites found in European coastal waters are harmless to consumers, but may have negative condition effects (macro-parasites) and cause higher mortalities (micro-parasites) in infested hosts (Brenner *et al.* 2009). Beside the potential harmful effect on a host, some macro-parasites pose an aesthetic problem, since they are visible due to their bright colour (*Mytilicola intestinalis*) in raw mussels or due to their size (*Pinnotheres pisum*) (Brenner & Juetting 2009). In Blue Mussels in some intertidal and nearshore areas parasites can be numerous. Buck *et al.* (2005) and Pogoda *et al.* (2012) have shown that offshore grown mussels and oysters were free of macro-parasites and that infestation rates increased with proximity of the sites to shore, respectively; intertidal mussels showed the highest numbers of parasites. The debate over the effects of parasites on the energy status and overall health of the host is still open as data needed to elucidate these issues is still lacking.

4.5.4 Technical Research on OA

Although France has over 30 years of experience in farming offshore, the offshore technology is still new, because worldwide, this sector is at an early stage of development. Even if production at individual farm sites is small by comparison with nearshore farms, in the future, offshore farms which are either proposed or under development might, at full production, exceed the capacities of many nearshore farms (Cheney *et al.* 2010, Buck *et al.* 2010).

Table 4.3. Locations and species cultured at selected offshore shellfish farm sites (Cheney *et al.* 2011). Data source: Buck 2007 a, b; Davis 2003; Jeffs 2003; Plew *et al.* 2005; Thompson 2006; Van Nieuwenhove and Delbare 2008, Pogoda *et al.* 2011.

	Location	Species	
North America	Atlantic Canada	Blue mussel	*Mytilus edulis*
"	New England USA	"	"
"	Santa Barbara channel, USA	Mediterranean mussel	*M. galloprovincialis*
"	"	Pacific oyster	*Crassostrea gigas*
"	Strait of Juan de Funa, USA	Rock scallop	*Crassedoma giganteum*
Europe	France, Mediterranean coast	Mediterranean mussel	*M. galloprovincialis*
"	Germany, North Sea	Blue mussel	*Mytilus edulis*
"	Belgium, North Sea	"	"
"	Ireland	"	"
"	Portugal, Spain, and Italy	Mediterranean mussel	*M. galloprovincialis*
Asia	Japan	Japanese scallop	*Patinopecten yessoensis*
Oceania	New Zealand	Greenshell mussel	*Perna canaliculus*
"	Australia	Pacific oyster	*Crassostrea gigas*
"	"	Blue mussel	*Mytilus edulis*

Traditional longline techniques cannot cope with the increased exposure to wave action, currents and wind which are found in offshore environments. The challenge in developing offshore shellfish systems is to create a combination between a system that is strong enough to withstand the offshore conditions and one that is not too expensive, easy to access and to manipulate by the farmers. Rather than using very strong and heavy materials there is a need for smart solutions such as keeping the tension on cables low, preventing the occurrence of sudden peak forces on the cables and preventing the loss of the structure under sea state and current forcing (Bompais, 1991, Hampson *et al.* 2010).

In the seventies, CNEXO (French Institute) conducted extensive research on longline technology including many field trials (Bompais, 1991). This resulted in commercial operations along the French Mediterranean coast and along the Atlantic coast (Pertuis Breton). *Cepralmar*, in France, developed submerged longlines (Figure 4.5a) which have been in use commercially since the eighties along Mediterranean French coast, where the backbone rope is submerged to a depth at which wave action has less of an impact on the system. A disadvantage of these systems is the depth needed: the backbone rope must be at least 5 meters below the sea surface and therefore, it cannot be used in shallower offshore areas (e.g. the Belgian offshore area D1 has a depth of 8 m only as well other areas in the Wadden Sea of The Netherlands, Germany and Denmark). Bompais (1991) and the IFREMER Technology team more recently (since 1985) modified the system for the Atlantic coast, conceiving sub-floating longlines (Figure 4.5b): in the subfloating longline, the floats are pencil-shaped to reduce wave action on the longline (Bompais, 1991) (Figure 4.5). The submerged longlines developed by Langan & Horton (2003) are being used in pilot projects throughout the world (Hampson *et al.* 2000; Buck 2007b). To minimise wave impact on the longlines all surface-reaching objects on the backbone rope such as buoys could be submerged (Figure 4.6). In this case, special attention should be given to surface guard buoys to prevent vessels from destroying the systems. Another submerged construction is the longline system in a segmental design with a variety of different buoys (Buck 2007). This system was tested in hostile environments 17 nautical miles off the coast and withstood waves up to 8 m and current velocities up to 1.5 m/s (Figures 4.7-4.8). In Iceland, longlines will be submerged 10 m under the sea surface in winter season. In the Canadian project in the Baie des Chaleurs region of Quebec, collectors are attached to buoys from above and secured vertically by large ropes attached to anchors. As the spat grow, the lines become heavier and drop deeper, allowing the compensation weights to reach the seafloor, which stabilizes their vertical position and helps protect mussels from predators and the seafloor thus avoiding loss (Figure 4.9). This system, because of the minimal handling required and automatic depth adjusting, as determined by weigh, is suitable for high energy sites. In Newfoundland and Labrador there is interest in expanding mussel production but access to inshore sites is limited. Moving into more exposed locations requires submersion technology infrastructure to deal with threats of fast moving ice conditions associated with the winter and spring months in the North Atlantic. Companies in Newfoundland are involved in a pilot study to develop a submersible system that enables the mussel lines to be dropped to depth to avoid moving ice conditions and raised for service and harvesting and to develop this system for commercial application (AIMAP Projects 2008-N-05 and 2008-N-01).

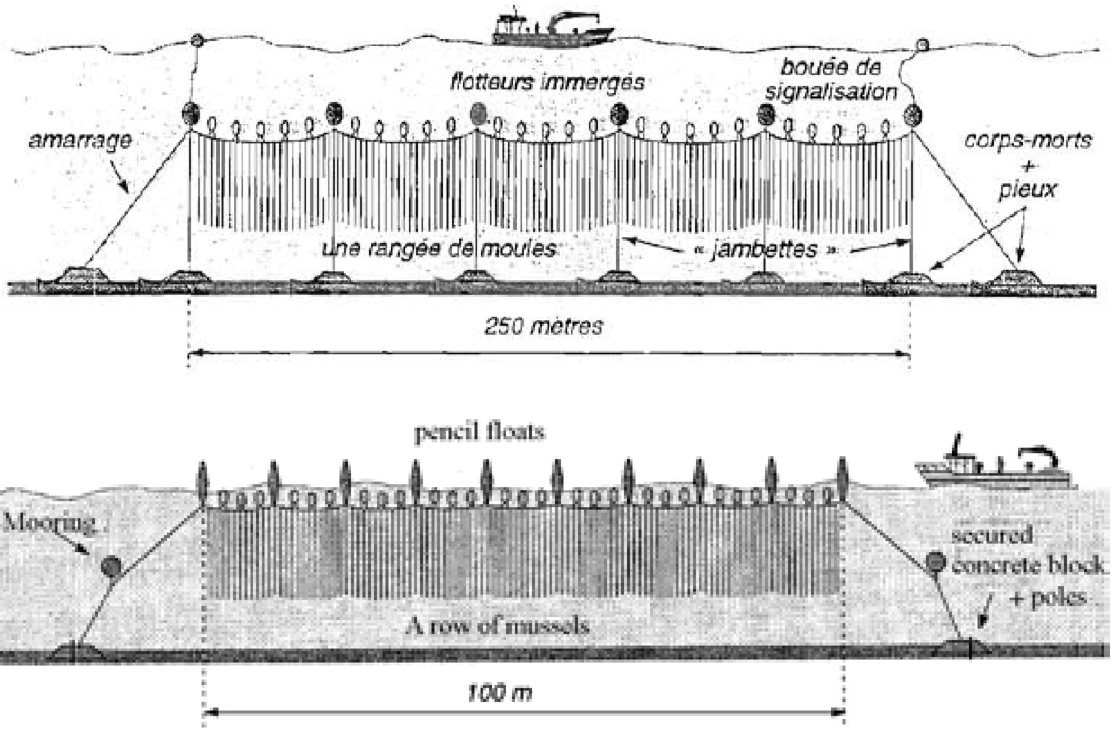


Figure 4.5. (a) Mediterranean subsurface (= submerged) longline and (b) Atlantic subfloating longline (source: Bompais, 1991 and Danioux *et al.*, 2000).

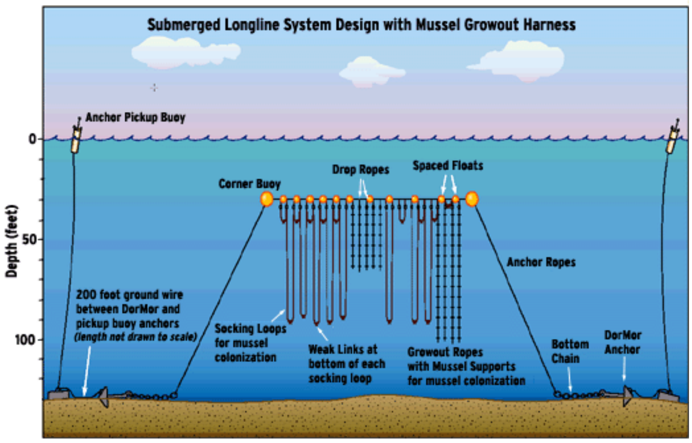


Figure 4.6. Subsurface longlines. No buoys attached to the backbone rope reach the surface to minimise wave impact. Source: Hampson *et al.* 2010.

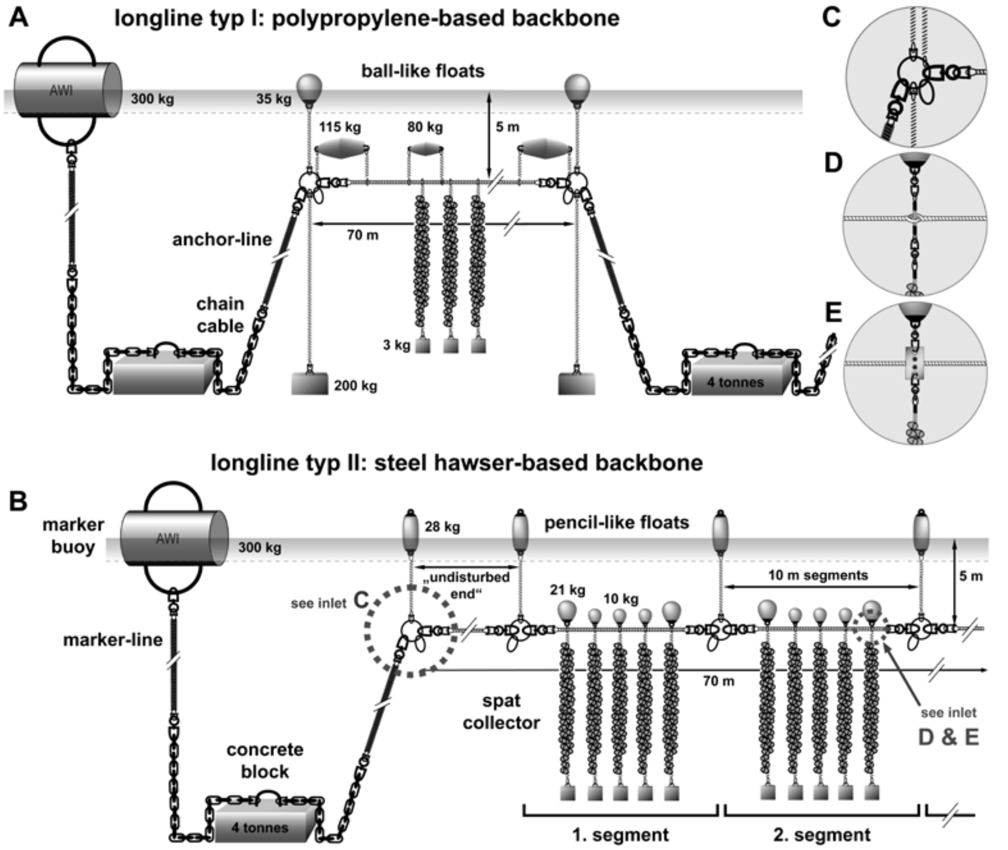


Figure 4.7. Submerged longline system designs with spat collector harness a polypropylene-based longline above (longline I) and b a steel hawser-based longline. The insets show the c coupling elements and d, e the connection of floats and collectors. c Polypropylene and steel hawser, d, e steel hawser (Buck 2007).

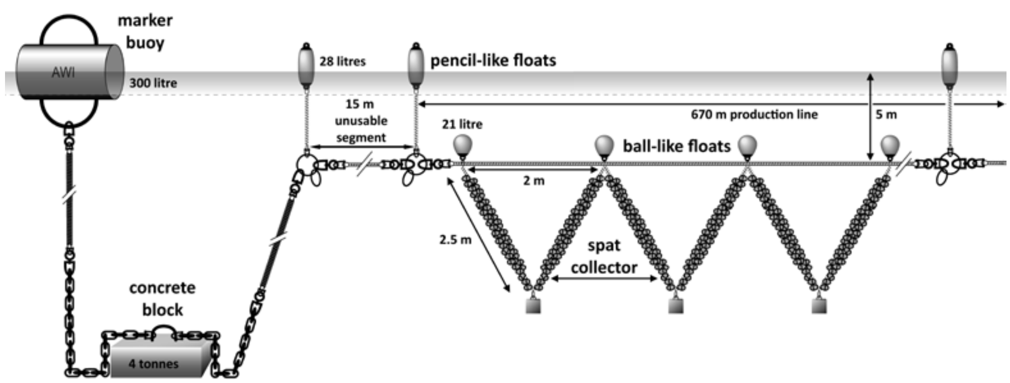


Figure 4.8. Example of a submerged longline system design with a V-shaped spat collector harness. In this image only a part of the 700 m long longline is presented (not to scale) (Buck *et al.* 2010).

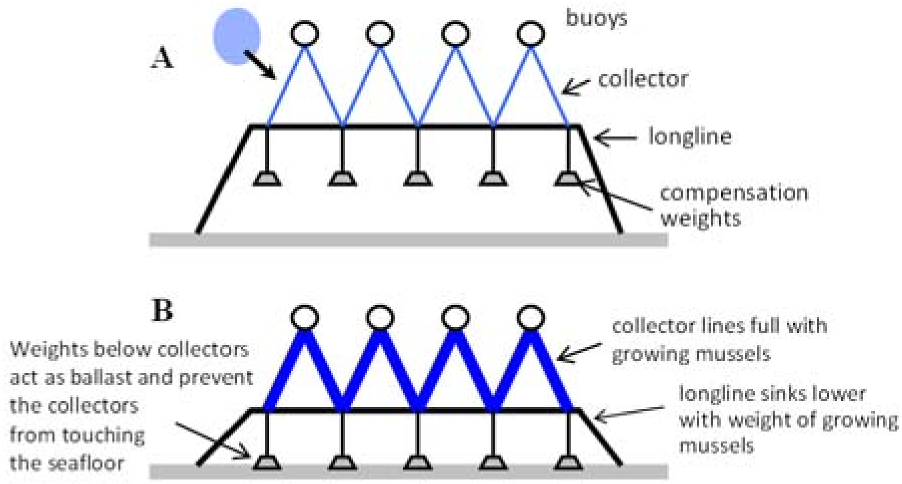


Figure 4.9. Schematic view of a self-regulated longline. A: High in the water column, collecting spat (blue spot depicts mussel larvae ready to settle on the collector ropes). B: In normal operating position during mussel growth.

As an alternative to the longline techniques various other constructions have been developed and tested. In Belgium a buoy for mussel farming was developed in 2006. The buoy, with a height and diameter of 5 meters contains about 400 m of mussel rope and weighs about 7 tonnes. The buoy is anchored with a concrete block and an anchor to prevent drifting. For harvesting, a large vessel with a crane takes the buoy out of the water. The buoy is placed on a carousel that allows the unwinding of the mussel rope from the buoy (Figure 4.10). A main disadvantage of the buoys was their weight which required an expensive and slow working vessel with a crane. This, combined with several other problems such as anchorage, electrolysis, as well as the few working days with calm sea, led to the abandonment of this technique in the spring of 2010.

Another Belgian farmer constructed a large pontoon containing 8 cages in 2007. The cages were equipped with vertical poles wrapped with mussel rope (as is done in the bouchot-technique). The pontoon had its own mechanism, connected to the ship's hydraulics to lift the cages from the water, allowing the farmers to use a smaller vessel. In 2011 the pontoons needed a complete revision because they were heavily affected, biologically and physically, by the North Sea (Figure 4.11).

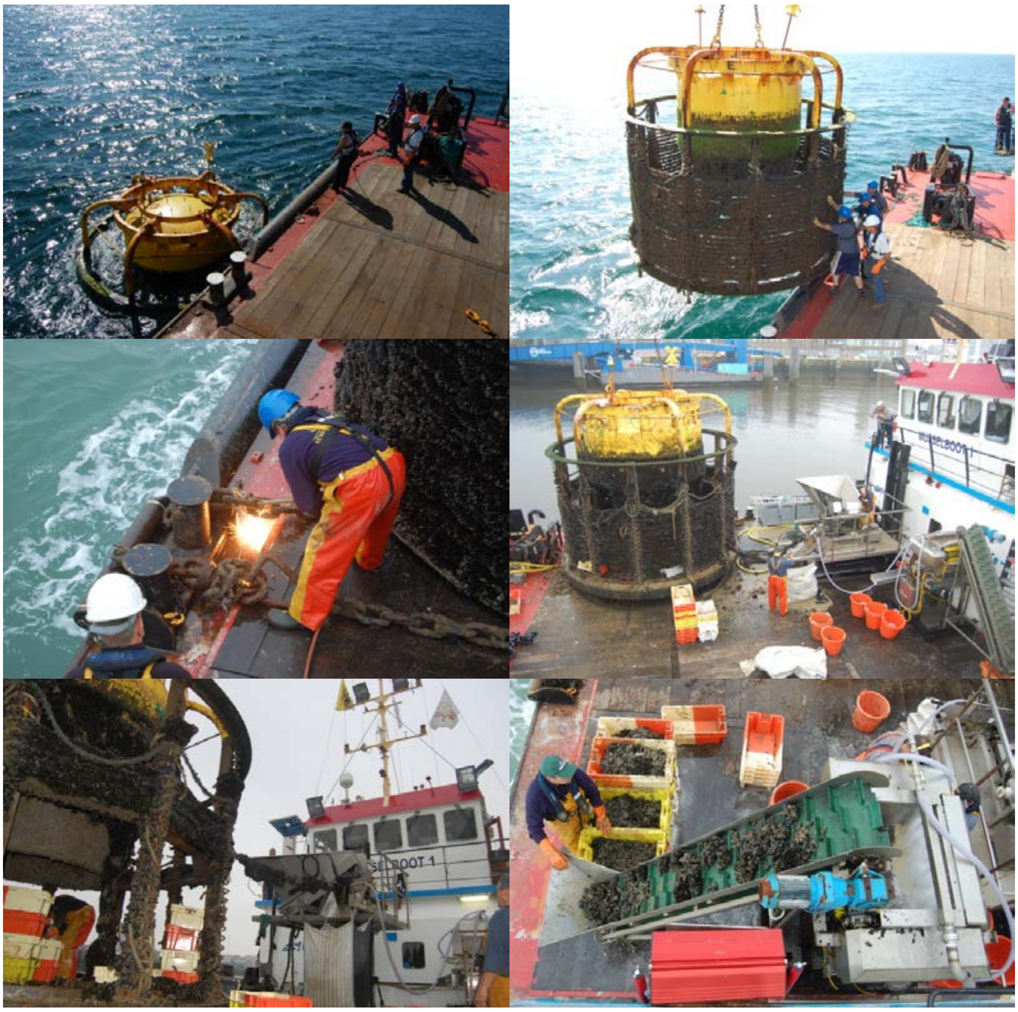


Figure 4.10. A series of pictures of the harvest of the SDVO buoys (photographs: ILVO, Kris Van Nieuwenhove).

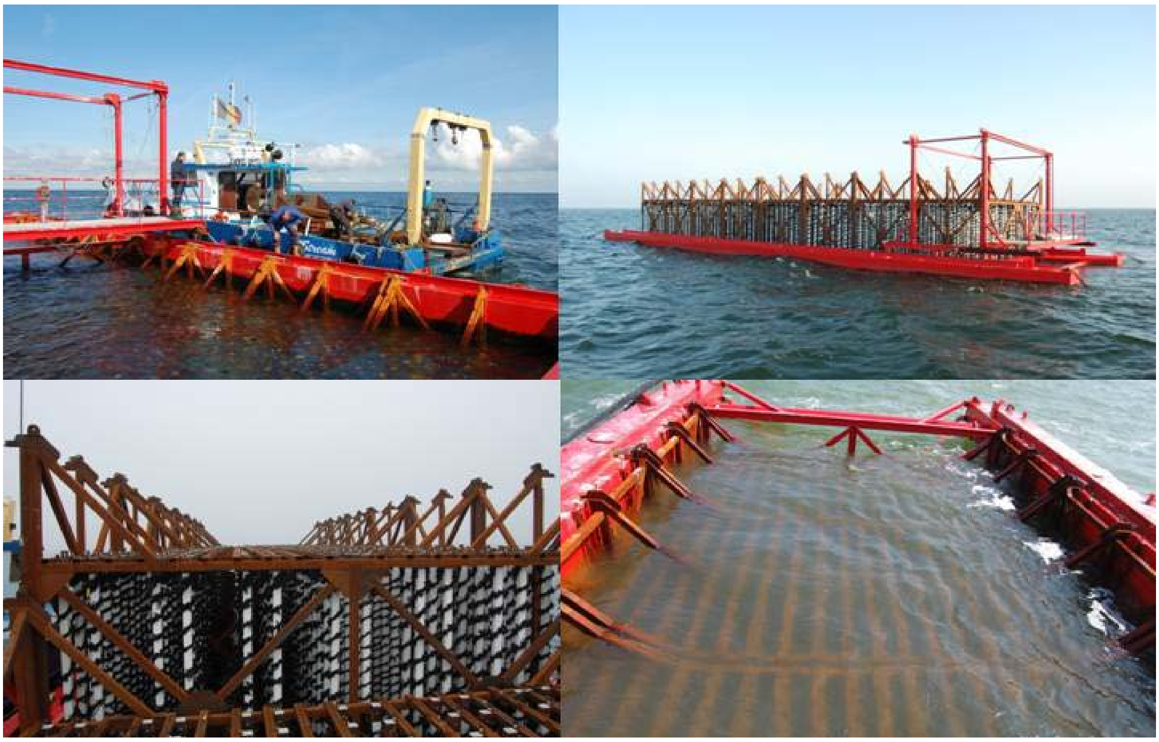


Figure 4.11. The Reynaert-Versluys pontoons (photographs: ILVO, Kris Van Nieuwenhove).

The "Mosseldobber" (the mussel float, Figure 4.12) was developed during the project "Mosselkweek in open zee" (mussel farming in open sea). The construction consists of a 5 meter long plastic tube whose top is filled with the floating polystyrol (styropoor) and whose bottom is filled with sand and vertical ropes are attached on the outside. Originally, these were constructed from wood. In 2003 and 2004 the construction was tested in the Oosterschelde where the float worked well. In 2005–2007 the test was repeated in the Voordelta (Steile Hoek) and the Wadden Sea (Malzwin), but the floats were lost (Delbare, 2011).

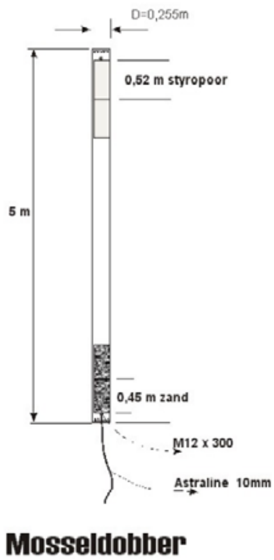


Figure 4.12. The mosseldobber (mussel float); (Source: Den Boon).

Another construction was developed by Gafmar Seafood which consists of a buoy connected to a ring. This first ring is linked to a second ring with a chain (Figure 4.13). Between both rings mussel rope is fixed. In normal conditions the construction is positioned vertical in the water but for harvesting the construction can be lifted horizontally next to the working ship (Lont, Pers. Comm.)

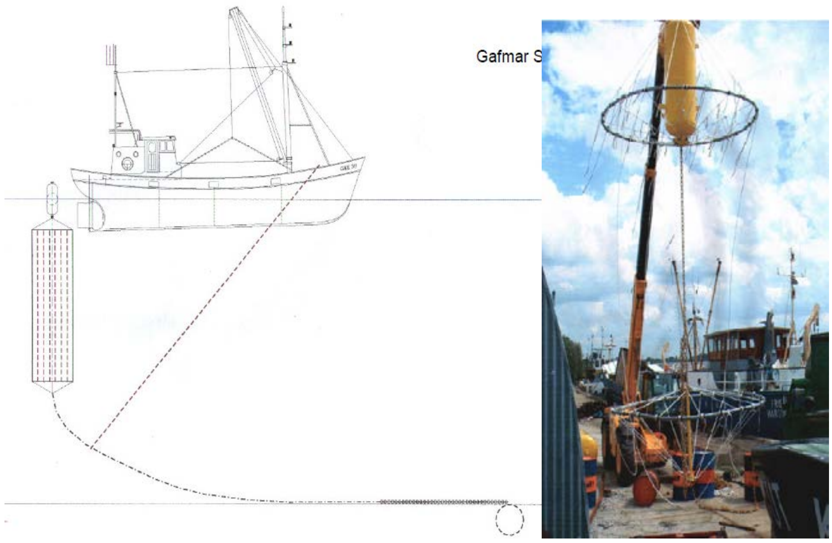
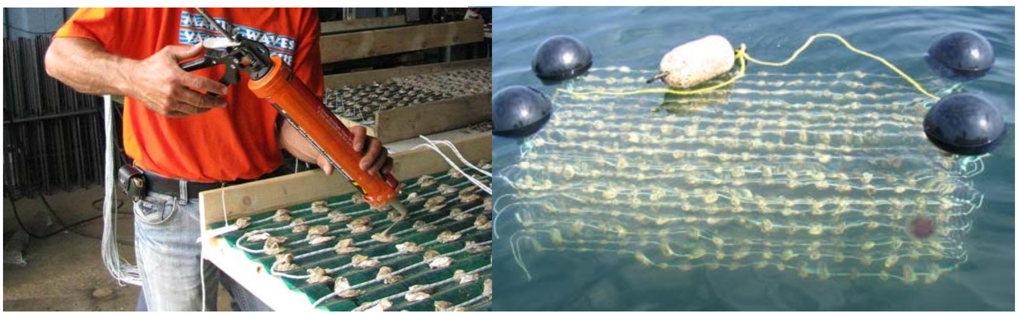


Figure 4.13. The Gafmar Seafood design (source: Den Boon).

Because of the strong forces working on the culture systems anchoring is a typical problem for offshore shellfish farms. Different anchoring systems are in use, including heavy concrete or granite blocks, anchors and poles drilled into the sea bed. These systems are the foundations of any large constructions. The anchoring type used depends on the nature of the sea bed, systems available and legal restrictions.

Initiatives to develop offshore culture of the Eastern Oyster (*Crassostrea virginica*), which are traditionally cultured in sheltered bays and estuaries are underway in Canada. A project to examine the performance of oysters cultured at an exposed (offshore) environment is compared to those cultured at a sheltered (inshore) site is ongoing using a grow-out method developed in the étang de Thau in France and modified for the New Brunswick environment (Figure 4.14) as described in Mallet and Doiron (2009) (ACRDP Project Number MG-09-02-004).



a) **b)**

Figure 4.14. Modified French grow-out method a) Oysters being glued on a string b) Unit used for the study.

Due to the fact that very often weather conditions are harsh and hamper the installation of common technologies, offshore wind farming has been proposed for co-use with aquaculture (Buck 2002, 2004). Establishment of offshore wind farm turbines provides space and attachment devices for mariculture facilities and therefore minimizes the risks originating from high-energy-environments (Buck *et al.* 2006). Potential synergies include the placement of mariculture technology in defined corridors between wind farm turbines or attachment to the foundations of windmills (Buck *et al.* 2004); (Figure 4.15).

In Denmark desk-studies and field investigations have analyzed the potential for offshore production of blue mussels inside or outside wind farms. Research covers biological analyses of production potentials and analyses of how maintenance operations and physical conditions set the limits for shellfish production. Furthermore the analysis identifies potential production methods.

Aquaculture in a wind farm must, at present, adapt to the conditions set by the wind farm operators (Stenberg *et al.* 2010) who may or may not decide to open the area or they may decide to open it under specific conditions. Due to the high economic output of wind farms it is central for the operators to minimize periods of no production due to hardware break-down. This means that the aquaculture may adapt to 1) planned routine maintenance of wind turbines and 2) maintenance due to break-down. Maintenance can include use of smaller vessels that do not interact with aquaculture activities, but may also require huge platforms, that utilize most of the space between wind turbines (480 to 800 m), anchoring and navigation. As a consequence, no aquaculture or only activities with mobile units may take place between wind turbines. Investigation of the physical conditions between locations, indicate that wind- and wave conditions may change significantly, contrasting offshore locations in the Baltic to the North Sea (Stenberg *et al.* 2010). Consequently, number of days for which aquaculture can operate varies as a function of location, season and technology at the production platform.

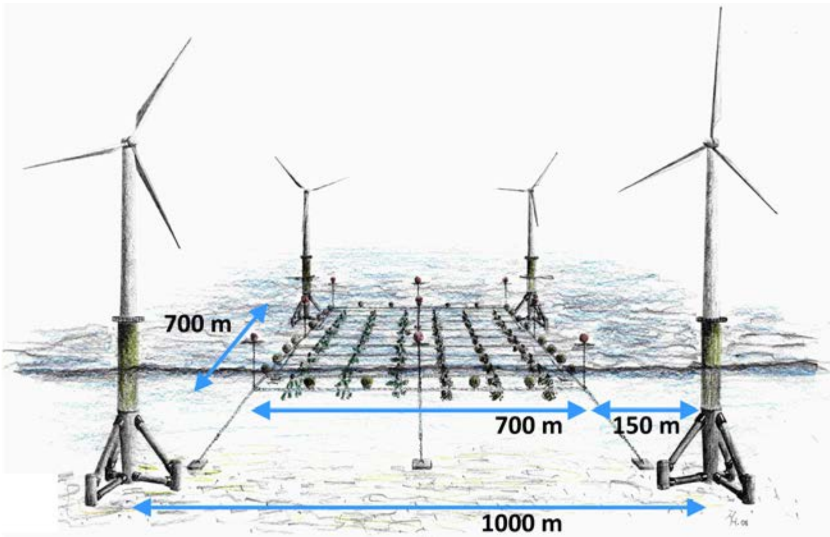


Figure 4.15. Image presents a design of a single mussel plot within a group of four wind turbines (not to scale). Modified after Buck *et al.* (2010).

4.5.5 Economic considerations of OA

More than 50% of the annual worldwide harvest of mussels is produced in nearshore or sheltered areas in Europe. Offshore mussel farms operating on commercial scales are found in France and Belgium. In addition, in the UK a permit for an offshore mussel cultivation site was granted in 2010 to Offshore Shellfish Ltd, to produce mussels off the coast of England. Other experiences of an offshore farm, set up outside of Europe, exist off the coast of New Hampshire (US), but this farm is no longer in operation. Therefore, calculating the economic potential of farms within Europe when moving offshore is only possible on a theoretical basis. Buck *et al.* (2010) calculated the potential and economic feasibility of mussel cultivation as a co-use in offshore wind farms. This study compiled the basic data for offshore mussel cultivation in close vicinity to a designated offshore wind farm in the open sea of the German Bight and employs different case-scenario calculations to illustrate the impact of changing parameter values on overall profitability or non-profitability of this activity. Primary focus was placed on the production of consumer mussels but seed mussel cultivation was also taken into consideration. This study concludes with providing some recommendations on how favorable terms or actions could further improve profitability of offshore mussel cultivation. Altogether, the results are intended to shed light on business management topics that future offshore mariculture operators, such as traditional mussel farmers, should follow in order to be efficient.

In relation to a shift in production structure from productions in areas protected from wave and wind exposure to offshore locations in a harsh environment, the impact of a range of factors have to be evaluated (Table 4.4).

Table 4.4. Economic perspectives of offshore aquaculture evaluating how establishment, maintenance and production will be affected changing production structure from offshore mussel production to coastal production. Based on Buck *et al.* (2010).

Item	Description	Cost development
Technology and operation	Due to wind/wave exposure the number of working-days will be reduced. Increased dimensions of installations to improve robustness to wave action Investment in larger vessels Reduction in closings for harvesting due to algal toxins	Increase cost Increase cost (x1.3) Increase cost(x1.4-3.8) Reduce cost
Biological processes	Change in growth Change in mortality Change in invertebrate predation Increased fish predation (Mediterranean-Seabream) Reduced bird predation (eg eider)	Reduce cost Reduce cost Reduce value May increase value
Quality of products	Hazardous substances Shell thickness and robustness to processing	Neutral or increased value Increased value

Contrasting the key economical numbers for mussel production in offshore production and protected fjord systems may be informative in order to predict how fast a change in production structure can take place and how fast the need of development of new technology arises. Buck *et al.* (2010) have analyzed the economic feasibility of long line production in an offshore area in the German Bight (see Table 4.5 for basic data). The production potential of a unit was 1189 tonnes, and the prices for production were 835 500 € and 4 million € for a 43-m vessel.

Table 4.5. Basic data for economic evaluation (Buck *et al.* 2010).

TABLE 1 Basic Data for the Offshore Site Nordergründe

Details of the Mussel Farm	Value
Distance to the City of Bremerhaven	17 nautical miles
Number of wind turbines	18 (5 MW class)
Distance between turbines	approx. 1,000 m
Minimum spacing between turbines and any aquaculture co-use	150 m
Size of aquacultural area (single mussel plot)	$700 \times 700\,m = 490{,}000\,m^2 = 0.49\,km^2 = 49\,ha = 121$ acre)
Number of single mussel plots	4 (=196 ha = 484 acre)

In 2007 the production structure and economy in Danish mussel farms in Limfjorden were analyzed indicating that the cost of establishing a mussel farm (250x750 m) was approx. 160 000€ and the cost of vessels including sorting and socking equipment was approx. 260 000€ (Christensen 2008). During recent years several larger mussel farms have invested in large vessels for harvesting, and the cost of vessels ranged from 260 000 to 730 000€. The production capacity is approximately 300 tons. Contrasting the cost of establishing an offshore farm and a mussel farm in a protected fjord indicate that the cost of the production unit is a factor 1.3 higher for offshore production when the cost is adjusted for production potential. The cost of a vessel is a factor 3.8 times higher for offshore production assuming the mussel farmer in the fjord only invests in a small vessel for maintenance and rents a larger vessel when harvesting. If the mussel farmer in the fjord invests in a vessel for harvest, the cost for establishing a production in offshore areas is 1.4 times higher than in protected fjords. It must also be kept in mind that foreseen production on offshore long lines may be hampered by predators, like seabream, which are more numerous in these areas (French Mediterranean offshore culture of mussels has been almost completely depleted since the nineties).

4.6 Site-Selection Criteria

Successful establishment of offshore aquaculture, like any other form of culture, requires that basic site selection criteria are met. This includes meeting the requirement for carrying capacity compliance (physical, economical, ecological and social) and ensuring the production of high quality products that are safe and healthy for human consumption. Further, and more generally, offshore aquaculture should fulfil the ecological, economical and social requirements of sustainable aquaculture.

4.6.1 Bio-technical criteria (for animals and human equipment)

"Bio-technical" opportunities and constraints are derived by crossing the requirements (or demand) of the cultivated species and husbandry gear/equipment on one hand with the environmental conditions of sites on the other. Parameters for consideration are physio-chemical conditions and biological conditions and may include:

Gear /equipment:

- Special seed collectors for use offshore (e.g. low drag design);
- No anti-fouling.

Physio-chemical and biological conditions:

- Capacity of mussel conglomerates to adapt to strong currents. If available and native, the use of strains which resist strong environments (e.g. *M. galloprovincialus - M. edulis* hybrids).
- Biology and physical oceanography controlling larval availability, food, toxic algae, predators, parasites, water temperature, salinity, the flux, mixing, and quality of suspended particulate matter, wave height, current velocity, inorganic sediment load, and dissolved materials (oxygen and some contaminants).
- Stable environment (oxygen, temperature, salinity, food).
- Cleaner environment (urban sewage, contaminants).

4.6.2 Site-selection models

To identify available offshore areas, including Offshore Wind Farms (OWF) a Multicriteria analysis (MCA) can be conducted, producing a suitability index for offshore aquaculture. Benassai *et al.* (2011) conducted an index for the North Sea including factors such as sea surface temperature, chlorophyll concentration, topography and wind energy. Based on these data a suitability index was determined, indicating that the most suitable areas are found in the southern North Sea and along the Danish west coast (Figure 4.15). When using MCA for aquaculture purposes the index should be expanded to also identify suitable areas in the OWF where conflicts are least likely to occur with maintenance activities and to be in compliance with safety restrictions in the OWF. In the EU-project COEXIST spatial distributions of maintenance activities are mapped by the use of AIS information, which can map the positions of service vessels.

The type of aquaculture is an important consideration in considering the type of conflict likely to be encountered. Bottom cultures of bivalves with no structures on the surface will only conflict with OWF maintenance when vessels are present during transplantation, harvest or inspection. Longline production or production in cages on the surface will conflict with OWF maintenance due to the presence of physical structures on the surface and frequent and vessel-operations. Additionally, development and use of mobile production units may significantly increase user conflicts.

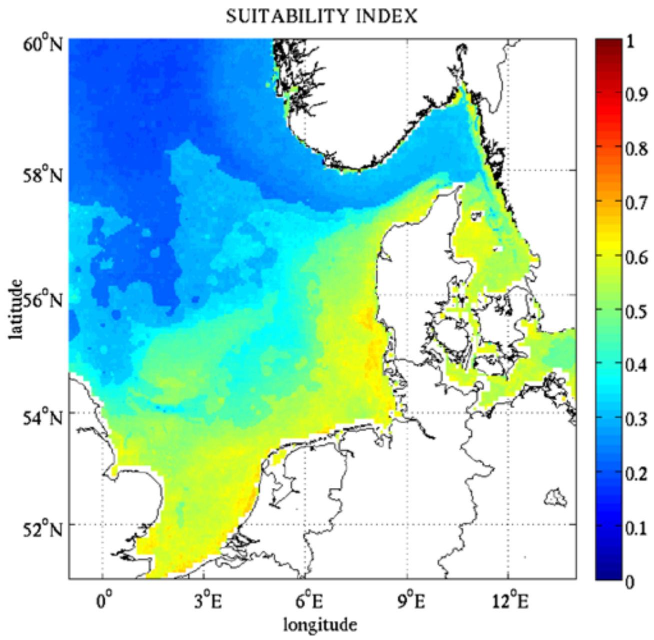


Figure 4.15. Map of the suitability index for the North Sea and adjacent areas (Benassai *et al.* 2011).

4.6.3 Consumption suitability

A detailed analysis of the overall health of the cultivated candidate together with data about parasite infestation, bacteria, virus and toxic algae concentrations can be used to characterize site conditions (Brenner *et al.* 2009). All investigated mussels (*Mytilus edulis*) and oysters (*Crassostrea gigas, Ostrea edulis*) are free of parasites when cultivated in an offshore environment (Buck *et al.* 2005, Brenner *et al.* 2009, Pogoda *et al.* 2012). Organisms growing under optimal water conditions achieve high growth rates and provide best product quality for consumers. Using these data, reliable predictions are possible and economic risks for potential offshore farmers could be reduced.

4.6.4 Ecological criteria

Possible interactions between aquaculture and wildlife preservation, particularly species at risk, and critical habitat also have to be considered. With OA, these interactions may be reduced in many cases. Protected diving birds may still eventually interfere if they locate an offshore culture site.

The planning of OWF includes detailed environmental impact assessment (EIA) studies, including descriptions of the area. These EIA studies can be incorporated in to the planning for offshore aquaculture.

4.6.5 Economical criteria

Offshore culture systems will require higher investments costs. Therefore, site criteria of a culture plot should be well known in order to accurately calculate economic risks. The specific conditions of OA have a direct impact on the costs of production (investment in adapted boats and equipment, energy, cost of transport, etc.). The increased cost or reduced lifespan of culture gear (e.g. longlines, buoys), transportation (ships) or eventually, the work conditions (harsh environment, limited time at sea due to harsh weather conditions for servicing the site) are a specific constraint that may be a limiting factor.

In the case of opportunistic use of existing offshore facilities (e.g. wind turbines or oil and gas platforms) the overhead cost should be reduced (e.g. Buck *et al.* 2010) and cooperation of OWF and aquaculture may provide opportunities to significantly reduce cost. In contrast, the increased productivity of sites may enhance production rates and quality of OA products (which could eventually be recognized through labels or certifications) and may yield better commercial prices (e.g. bio-products, product differentiation).

4.6.6 Social and ICZM criteria

As with the use of any site in the public domain, identified OA potential zones require collective agreement before allocation (with specific local rules of decision). For offshore sites, conflict should be reduced compared to onshore or nearshore aquaculture due to less amenity and patrimony issues. In any case, traditional users such as fishermen will still likely show an initial reluctance, even if they are involved in the project. One solution could be a joint operation such as co-management.

In the ICES areas, offshore aquaculture is not included in marine spatial planning. Few countries have fully evaluated the potential of using OWF for mussel production. A report from The Scottish Government (2011) evaluated the potential for aquaculture production in OWF and concluded that combining offshore wind farming and marine aquaculture is an opportunity to share stakeholder resources which could lead to greater spatial efficiency in the offshore environment, thus increasing income generated from the OWF. It is further concluded that the technology is premature and may also create conflict with other users, such as shipping, by creating a navigational hazard. The Crown Estate currently prohibits any other income earning activity by the OWFs in the lease area and so a change in law would also be required to allow aquaculture in OWF in Scotland.

4.7 Recommendations

- At present, several countries have initiated research to evaluate the potential for offshore aquaculture of bivalves. The research is dominated by reviews and desk studies, and few resources are invested in tests in the field. WGMASC should initiate a focused effort to identify the best offshore production concepts and cooperation in field tests of such a concept can improve the quality of the knowledge to the issue.
- Several bottlenecks for an offshore production are identified including the increased cost of establishment and maintenance of systems. On the other hand a rethinking of the logistics in relation to processing and transport to the marked may identify solutions that compensate the increased cost.
- In the next decade an increasing high numbers of marine wind farms will be established in offshore areas. The wind farms may potentially support a production of bivalves. WGMASC should initiate an analysis of the potential for bivalve aquaculture in those wind farms. The analysis should focus on blue mussels, but also include other shellfish species, such as European and/or Pacific Oysters.

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Appendix A

This is a draft version of the Preamble of *Bremerhaven Declaration* on the future of global open ocean aquaculture. The final version includes a series of recommendations and justifications and will be uploaded on the homepage of the Aquaculture Forum Germany (www.aquaculture-forum.de). At this status modifications, changes, comments will be allowed for everybody before the declaration will be published in aquaculture related journals in 2012. At this status the following scientists are in charge of the current content of the *Bremerhaven Declaration*: Harald Rosenthal, Barry Costa-Pierce and Bela H. Buck.

BREMERHAVEN DECLARATION
on the Future of Global Open Ocean Aquaculture

Preamble

Workshop I of the Aquaculture Forum Bremerhaven was attended by about 100 participants from 16 countries, representing experts from industry, science, investors, regulators, and consumers. The initial concept for preparing the declaration was conceived at the "Marine Resources and Beyond Conference" held in 2011 and finalized in 2012 during the "International Workshop on Open Ocean Aquaculture", both held in Bremerhaven, Germany.

The participants of the workshop discussed a number of pertinent issues related to open ocean aquaculture while:

-recognizing that global food security, human health and overall human welfare are in serious jeopardy since the production of living marine resources for vital human foods cannot be sustained by natural fisheries production even if these resources are properly managed at levels of optimum sustainable yields;
- realizing that the gap between seafood supply and demand is increasing at an alarming rate as these are nutrient-dense foods considered extremely important for human health and well-being. On the other hand the development of aquaculture has been remarkable and today provides more than half of all fish destined for human consumption;
- confirming that conventional land-based and coastal aquaculture will continue to grow, thereby playing in the future a growing role in quality food supply. However, this much needed development will only delay the widening of the gap in seafood supply and unconventionally new and modern technologies such as offshore farming systems are required to significantly assisting in closing this gap.
-noting that the world is too dependent however on aquaculture development and its exports, as aquaculture is threatened by coastal urbanization, industrialization, and water pollution. Weighing these trends we believe that it is urgent that the world develop offshore aquaculture, while complying with the FAO Code of Conduct for Responsible Fisheries and Aquaculture as well as with other environmental regulatory frameworks in support of sustainable aquaculture development;
- finding that Offshore aquaculture will require much higher inputs of capital but also needs a new level of cooperation from a wide range of social, technological, economic, and natural resource users.,
-discovering that over the past decade major advances and new concepts have evolved, and several of them have been successfully tested at the pilot scale level, while others have failed.
- learning that these experiments and scale-up trials have led us to believe that offshore aquaculture does have substantial potential to bring global aquaculture production to new levels to meet future human needs;
-believing firmly that strategies need to be developed with strong participation of all affected stakeholders interested in the social-ecological design and engineering of innovative offshore food systems;

- recognizing that the integration of offshore food and energy systems (e.g. aquaculture systems and windfarms; oil and gas) appear to be especially promising , but will require a high level of innovative technology, the use marine spatial planning, and transparent, adaptive management for spatial efficiency and conflict resolution;
- concluding also that open ocean aquaculture if intelligently designed can be incorporated into overall cooperative fisheries restoration and management strategies.

Following these discussions the undersigning Workshop participants (which included the core group of the global expertise on the subject) formulated a series of specific recommendations. We call upon national, international, inter-governmental agencies, as well as the industries, potential investors, scientists, regulators and NGOs of the respective countries to strongly support these recommendations with the aim to provide a healthy and environmentally sustainable bio-resource system that can substantially contribute to meet the future demands of our societies. We herewith request immediate action to provide the means and resources for implementing the recommendations listed below.

Appendix B

Strategy on the Cultivating of Danish Seas

Abstract to Mariculture Offshore Conference in June 2010 by Karl Iver Dahl-Madsen (President of the Danish Aquaculture Association), Flemming Møhlenberg (Head of Ecological Innovation at DHI), Per Bovbjerg Petersen (Head of Aquaculture at DTU Aqua)

Denmark is a global leader in producing healthy and tasty food with a low ecological footprint. We are a nation by the sea and living of the sea. We already have one of the most exposed and highly productive off-coastal trout farms in the world: Musholm A/S with a capacity of 3000 tons / yr in the open part of the Great Belt. We aim to continue to be part of the nations cultivating the sea by producing significant quantities of food, feed, chemicals and biomass such as fish, mussels and seaweed on off-coastal and off-shore locations.

The Danish sea territory is 105 000 km^2, about 2.5 times the land area of Denmark. By using 1 % of this area we can produce fish, mussels and seaweed to a value of 2 billion Euros pr. year. This production will account for 3 million tons of CO_2 pr. yr. corresponding to about 5 percent of the Danish CO_2 discharge. Furthermore, we can regain 100 000 tons of nitrogen and 10 000 tons of phosphorus from the sea and use it on land. The production will, as an example, substitute the use of 10 000 km^2 Brazilian rain forest, and save freshwater in an amount corresponding to 2.5 times the total water use of all Danish households. The associated industry will be located in rural and coastal areas, at present having difficulties in attracting people and companies.

We propose for the Danish Society to establish a platform for development of off-coastal and off-shore aquaculture technology. The development should primarily emphasize cost-efficient and robust culture installations to be situated at open sea, cultivation technology and fully automated farms using state-of-the-art robot and information technology. Secondarily, advanced biotechnology should be used for refining culture species methods and usage of the produced biomass. An investment and demonstration program for risk-sharing in the pioneering installations should be implemented too.

5 Review knowledge and report on the significance and implications of bivalve aquaculture transfers between sites (local, national, international) to wild and cultured bivalve stocks: implications (ToR c)

5.1 Background

Movement of shellfish around the world is an activity that has a long history (Wolff & Reise, 2002). The objective is always economic, to develop a sustainable food supply, to replenish a depleted stock, or to start a new culture. ICES Member Countries import live organisms from 32 countries and molluscs are among the most important taxa transported (WGITMO, 2006). The transport of different shellfish species including life stages from hatcheries, from field sites to new culture or wild fishery sites, often crossing international boundaries, has potential implications - through the introduction of shellfish and their associated organisms. These can include non-indigenous species, potentially toxic algae, viruses, bacteria, disease agents or parasites. Potential implications can be interactions with wild and cultured stocks (impact on recruitment, loss of cultivated organisms, sterilization, reduced fitness and fecundity, less meat content, competition, risk of predation, or change in genetic composition, diversity and polymorphism, and physiological and morphological traits; Ambariyanto & Seed 1991, Calvo-Ugarteburu & McQuaid 1998, Camacho *et al.* 1997, Desclaux *et al.* 2004, Dethlefsen 1975, Taskinen 1998, Tiews 1988, Wegeberg & Jensen 1999, Wegeberg & Jensen 2003).

The movement of bivalve by humans for aquaculture purpose can be usefully categorized into *transfers* and *introductions* (Beaumont 2000). A transfer is the movement of a sample of individuals from one area to another within the natural range of the species. The term transfer would also include the restocking of a habitat once known to have been occupied by a particular species. In contrast, the movement of individuals to another geographical region where that species has never been present before is referred to as an introduction. Tor c is focussing on transfers with their resultant impacts and is considering the long term impacts of introductions and transfers of shellfish, such as *Crassostrea gigas* within and amongst ICES countries (table of species will be included in 2012).

The concerns expressed regarding transfers and introductions are generally related to ecological impacts, genetic aspect and spreading of pathogenic agents. The transfers can have unexpected negative economic consequences. For example, the fouling organism *Styela clava* (tunicate) was introduced into oyster culture in France by shellfish transfer. It competes with the oysters for space, resulting in a significant decrease in oyster production (Davis & Davis 2010). The same has happened on Prince Edward in Canada(Ramsey *et al.*, 2008). Furthermore, marinas in the Firth of Clyde and on the Argyll coast of Scotland are to be surveyed by marine scientists following the discovery of a small colony of the invasive carpet sea squirt (*Didemnum vexillum*) (Beveridge *et al.*, 2011). It has spread around the world although it is thought to have originally come from Japan. Experience from Canada, New Zealand, continental Europe and Ireland has highlighted it as a potential nuisance species that causes economic and environmental problems. The removal of the large, gelatinous growths can be difficult and costly. It was found in the UK at Holyhead Harbour in North Wales in 2008 and more recently in the south of England (http://www.snh.gov.uk/news-and-events/press-releases/press-release-details/?id=195).

Presently, a number of ICES working groups are concerned with the topic of transferring marine organisms. The Study Group on Ballast and Other Ship Vectors (SGBOSV) work on specifically identified vectors of ballast water and hull fouling.

The Working Group on Introductions and Transfers of Marine Organisms (WGITMO) documents the spread of intentionally imported and/or invasive species introductions via the use of National Reports from many ICES countries. WGITMO's work focuses on the aquaculture vector and what happens when an invasive species is found in a water body (no matter what vector is involved) – origin and status of the invasion, potential impacts, options for mitigation and/or eradication, and sharing information with other countries. The WGITMO deals mainly with intentional introductions for e.g. aquaculture purposes, and works to reduce unintentional introductions of exotic and deleterious species such as parasites and disease agents through a risk assessment process and quarantine recommendations. The Working Group on Environmental Interactions of Mariculture (WGEIM) is examining the potential importance of bivalve culture in the promotion and transfer of exotic species (i.e. alien or introduced) and the resulting implications for bivalve culture and the environment. The WGEIM is also examining management and mitigation approaches for invasive and nuisance species that have been transferred to aquaculture sites.

The WGEIM (2006) report recommended to the Mariculture Committee that key representatives from ICES Working Groups dealing with aquatic exotic species, including the WGMASC, should meet to, among other tasks, identify information gaps and recommend specific research goals. The MASC working group concurred with this recommendation and recommended in 2007 to the MCC that the WGMASC undertake a new ToR on this high priority topic, beginning in 2008, to avoid overlap between Terms of Reference. The relevant reports of WGEIM and WGITMO are summarised below.

5.2 Related reports of WGITMO and WGEIM

5.2.1 2007 of the WGITMO[1]

Some sections within this report can be referenced within ToR c) of the WGMASC, such as the ToR f) "Status of development of ICES Alien Species Alert reports" including the evaluation of impacts and to increase public awareness. The aim is to finalize the ToR f) report at next year's meeting. In subsequent years additional taxonomic groups may be identified those more likely to be introduced deliberately as food, or accidentally by other vectors.

The report focuses on various species, especially on the Pacific oyster *Crassostrea gigas* (including the biology, the introduction for aquaculture purposes, the consequences of Pacific oyster introduction, mitigations and restorations, and finally a prospective). Further the question of the introduction of *C. ariakensis* to some areas of the US, primarily as nonsterile triploids, can be considered (including an environmental impact statement with alternatives, scientific contributions in support of the EIS, and a review concerning the utility of ICES Code of Practice guidelines in the current process). This deliberate introduction offered an opportunity to evaluate: how well the Code of Practice (ICES) is being followed; the Code's strengths and weaknesses, and what can be said about the risks involved in the process that the US adopted.

5.2.2 2008 of the WGITMO

In the report new species introductions, via shellfish movements or transfers, are mentioned. For example a few specimens and egg capsules of the American oyster

[1] Other reports from previous meetings were not available via the ICES homepage.

drill, *Urosalpinx cinerea*, have been found in October and November 2007 at Gorishoek in the Oosterschelde, an area of shellfish culture in The Netherlands. One possibility is that *U. cinerea* was introduced with imported shellfish from south-east England.

Further, it was again highlighted that human activity within the shellfish industry, including the discharge of ballast water from ships, are major vectors in dispersals of non-indigenous species. This supports the hypothesis that the species have been inadvertantly introduced outwith their natural range as a probable result of mariculture trade and shipping activities.

The Pacific oyster *Crassostrea gigas*, which was introduced in the early seventies in many shellfish production areas in Europe, Canada and the USA, was mentioned as a case example of an organism that established successfully, rapidly reproduced and settled to the wild, ie outwith farm areas constituting "natural populations" in many areas.

5.2.3 2009 of the WGITMO

At the end of the WGITMO report 2009 there is a table displayed including non-native species identified as considered problematic. Some of the listed species were transferred or introduced by shellfish originating from aquaculture. Annex 5 of the report contains an alien species alert on *Crassostrea gigas*. One of the chapters in this alert concerns the world wide introduction of *C. gigas* for aquaculture purposes and a chapter on the consequences of this introduction.

5.2.4 2010 of the WGITMO

Assessment of the genetic impacts of introduced species on native taxa is a relatively new field of, as it has only been possible to detect genetic changes at the level of single genes, by enzyme electrophoresis, since the 1960s. Consequently, the least studied aspect of species introductions may be the genetic impacts they have on native species. Knowledge on changes in the genetic integrity of indigenous popula-tions resulting from species introductions and genetically-modified organisms is mainly limited to hybridization events. Hybridization was cited as the most common impact, with the highest occurrences from Germany, Latvia and Russia. By contrast, 25 countries/regions considered there were no known hybridization impacts, al-though this is probably due more to lack of awareness and an absence of studies to detect genetic interactions than no impacts.

Cowx, I. G., Nunn, A. D. & Angelpolous, N. (2008). Role of alien species in European aquaculture, with linkages to fisheries. Report to EC, 30 pp.

The introduction of species beyond their natural range is expanding rapidly, due to increased transport, trade, travel and tourism, and the unprecedented accessibility of goods resulting from globalisation (Leppäkoski *et al*. 2002; Copp *et al*. 2005). Biological invasions by nonnative (also called alien, non-indigenous, exotic, or introduced) species are widely recognised as a significant component of human-caused global environment change (IUCN 2000), and aquatic habitats are no exception in this regard (Moyle & Leidy 1992). Non-native species encompass a diverse range of taxa that threaten a wide range of aquatic and terrestrial environments. The introduction of such species can have far-reaching and often harmful effects upon the biological diversity and the function of invaded ecosystems, and cause significant losses in economic values (Pimentel 2000). For example, non-native species can act as vectors for novel diseases, alter ecosystem processes, reduce biodiversity, disrupt the cultural landscape, reduce the value of land and water for human activities, and cause other socioeconomic consequences for humans (McGinnity *et al*. 2003). As such, non-native species are now considered to be the second most important cause of global biodiversity loss after direct habitat destruction, and they can have adverse environmental, economic and social impacts from the local level upwards.

One area of major concern regarding the spread of IASs is through aquaculture practices. To continue to be active in the market, as well as increase the annual growth rate, the aquaculture industry needs to be innovative and develop new and cost-effective production methods. Novel species production is one area that is being considered, with a perpetual search for fish, shellfish (e.g. Mollusca, Crustacea and Echinodermata) and plant species whose biology is well known and that have already achieved or could achieve success in extensive/intensive cultivation. Once identified, such species are potential candidates for movement to new locations for the purpose of establishing new fisheries and new aquaculture resources. This presents several major challenges. The first is the ecological, environmental and economic impacts of introduced and translocated species, especially those that could become established in the receiving environment should they escape the confines of cultivation. Such new populations can have adverse impacts on native species and ecosystems. The second challenge concerns the potential genetic impacts of introduced and translocated species, relative to their mixing with farmed and wild stocks, and the release of genetically modified organisms. The third challenge concerns the inadvertent movement of organisms associated with the target (host) species; this includes both pathogens and other organisms that are transferred with the target species. The mass transfer of animals and plants without inspection, quarantine, or other management procedures, has inevitably led to the simultaneous introduction of pathogenic or parasitic agents, causing harm to the development and growth of new fishery re-sources and to native fisheries. These problems are further highlighted in the Second Report of the European Community to the Convention on Biological Diversity – Thematic Report on Alien Invasive Species, October 2021, and the Bern Conven-tion2. The latter listed aquaculture (fish, molluscs and crustaceans introduced for production, and disease organisms accompanying introduced species) as one of 15 pathways for intentional and unintentional species introductions.

Although non-native species are becoming the backbone of production in many parts of the world (De Silva *et al*. 2006; Nguyen and De Silva 2007), few studies have attempted to evaluate the contribution of non-native species in aquaculture as a potential driver for their dispersion and the consequent impacts on biodiversity. This report reviews the extent of use of non-native aquatic species in aquaculture and assesses their importance to aquaculture in Europe. The main outputs of the review are information to underpin assessment of the impacts of non-native species on natural aquatic ecosystems if the species escapes and become invasive.

5.2.5 2005 report of the WGEIM

The potential effect of transfer of non-indigenous species on wild and cultured stocks of bivalve was **not** discussed in the terms of references. However, in Annex 3[2] the international trade rules from the World Trade Organization (WTO), by the Office International des Epizootic (OIE) and the Code of Practice for the Introduction and

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

Transfer of Marine Organisms (ICES 2003) are mentioned (see description field below). This text can be adapted to shellfish aquaculture issues also.

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

Finally, ToR g) of the recommendations "investigate the hazards associated with mariculture structures in terms of habitat change/modification and assess their potential for accommodating invasive/nuisance species in a system - proposed in consultation with WGITMO should be investigated" will be of use for shellfish aquaculture issues.

5.2.6 2006 report of the WGEIM

The potential effect of transfer of non-indigenous species on wild and cultured stocks of bivalve was discussed in the terms of references f (former ToR g). Their aim was to "examine the **potential importance** of bivalve culture in the **promotion** and **transfer** of exotic aquatic species as well as the importance of these exotic species to **bivalve culture and the environment**". The focus was on exotic species with an emphasis on those that become invasive and nuisance. Management implications and mitigation strategies are also addressed. The information presented is largely based on oyster-oriented literature but has been expanded where possible to include other taxa. The report covers many aspects that are important to shellfish culture such as the effects of exotic species - including exotic macrospecies – animals and algae -, exotic phytoplankton and disease species, on fouling, competition, predation, algae smothering shellfish, introduction of phytoplankton that causes harmful algal blooms, mass mortality due to disease transfer (viruses, bacteria, protozoans, higher invertebrates) on cultured bivalves.

Here, it was recommended by the WGEIM to organize a meeting with the appropriate members of other working groups (WGMASC, WGITMO, SGBOSV) to discuss these topics and to prepare a joint document.

5.2.7 2007 report of the WGEIM

The potential effect of transfer of non-indigenous species on wild and cultured stocks of bivalves was not discussed. However, in ToR d (Further investigate fouling hazards associated with the physical structures used in Mariculture and assess their potential for the introduction of invasive/nuisance species into the local environment.) the concept of Integrated Pest Management is mentioned to decrease the impact of non-indigenous (and pest) species.

5.2.8 2008 report of the WGEIM

Following ToR a) "Indices for the environmental effects of mariculture" which also deals with the ddevelopment of practical indices related to the sustainability of aquaculture the WGEIM decided not to continue to include the transfer of diseases from farmed to wild stocks, declaring these issues to be outside the remit of WGEIM.

5.3 Focus of WGMASC

The focus of ToR d) is on the significance and impacts of bivalve aquaculture transfers between sites (local, regional, national, and international) to wild and cultured bivalve stocks. The transported shellfish are the vector for any associated organisms, while the target species (the wild and cultured shellfish) are monitored to assess any impact prior to and post deposit. Information is being collected on current *guidelines in place and records kept* in ICES countries related to the transfer of cultured species to assess those impacts. Effects of shellfish relocations (including epi-/endofauna, epiflora, associated organisms, diseases, parasites and viruses): on the *geographic distribution of marine organisms*; *indigenous shellfish stock traits* (impact on recruitment, loss of cultivated organisms, sterilization, reduced fitness and fecundity, less meat content, competition, risk of predation, or change in genetic composition, diversity and polymorphism, and physiological and morphological traits), and the *potential implications* for regional shellfish culture operations are considered. In addition, suggestions for *scientific tools to support policy decisions* and *recommendations to farmers and policy makers* on cultured shellfish transfer issues will be given. Since many of the topics mentioned above are already covered in part by the 2006 report of WGEIM, the work of WGMASC can be seen as an addition to this report.

5.4 Work plan and report outline

In 2008 the role of WGMASC in the implications of bivalve aquaculture transfers between sites (local, national, international) to wild and cultured bivalve stocks was defined; following the screening of the SGBOSV, WGIMTO and WGEIM reports and considering risks not covered by those terms of reference. In the ToR dealing with records and guidelines of bivalve aquaculture transfers between sites WGMASC could show that transfer activities take place on all levels (local, regional and international) in most of the ICES member countries. Thus, efforts were focussed on the implications of transfers on all scales. Since WGEIM has provided already detailed insides about the implications of bivalve aquaculture and the introduction and spread of exotic species hitchhiking as fouling organisms, WGMASC concentrated in 2009 and 2010 on transfer effects concerning the spread of organisms travelling inside of bivalves' shells (intervalval water, water of mantle cavern) and tissues. Further, we focused more detailed on genetic and recruitment impacts resulting from transfer actions. To progress this term of reference in 2011 the group considered additional probable impacts together with initiatives to manage the risks associated with the introduction of non-native or nuisance species. In addition, the assessment of resulting implications and the development of scientific tools for decision support was continued.

In the sections below potential effects of shellfish relocations on the *geographic distribution of marine organisms*, *indigenous shellfish stock traits* and the *potential implications* for regional shellfish culture operations are reviewed and reported on. In addition, scientific tools to support policy decisions on cultured shellfish transfer issues are discussed and recommendations to farmers and policy makers are given. This results in the following outline for the remainder of the chapter:

5.5. Potential effects and implications (both positive and negative)
5.5.1. Develop the stock and new habitats
5.5.2. Transfer of macro parasites and pests
5.5.3. Transfer of biotoxins, cysts, larvae and eggs
5.5.4. Transfer of micro parasites and diseases
5.5.5. Transfer of human pathogenic agents bacteria and viruses
5.5.6. Genetic effects of transfers
5.5.7. Impact of transfer on biodiversity
Topics to be included in 2012 are: effects on recruitment, competition, risk of predation, change in physiological and morphological traits
5.6. Scientific tools to support policy decisions on cultured shellfish transfer issues
5.6.1. Risk assessments
5.6.2. Epidemiology and models of propagation of invasive species
5.6.3. Surveillance and Biosecurity Measures
5.7. Recommendations to farmers and policy makers
5.7.1. Recommendations to farmers
5.7.2. Recommendations to policy makers
5.7.3. Maintain an open dialogue
5.8. Recommendations
5.9. Conclusions

5.5 Potential effects and implications

5.5.1 Develop the stock and new habitats

When movements of shellfish, transfers or introductions, are done intentionally, some benefit is expected, at least by the promoters of the operation. In this case, one positive effect is to induce or develop the stock and then harvest the introduced species. Another consideration concerns eventual positive environmental effects. The introduced species may create new habitats or expand existing ones: for instance, the "PROGIG" program (Proliferation of the Pacific oyster Crassostrea gigas in coastal MancheAtlantique French: assessment, dynamics, ecological, economic and ethnological, experience and management scenarios (Hily, 2005) on proliferation of *C.gigas* in the wild, in France, concluded that local biodiversity was increased in oyster banks (even if homogenization of biotopes at larger scale). The introduced species (in this case *Crassostrea gigas*) may also provide a range of ecosystem services, e.g. filtration benthic-pelagic coupling, that might previously have been provided by a shellfish species, e.g. *Ostrea edulis*.

5.5.2 Transfer of macro parasites and pests

The presence of "usually harmless – potentially harmful" organisms lead us to the problem on the existence of "stowaways", and the action of mechanical vectors. One organism will always carry another, and it seems impossible to obtain "clean" animals, in spite of long quarantines. An example of stowaways is hidden organisms in a consignment of bivalve spat. Frequently, batches contain more species than those they are supposed to contain, even if the batches have been (roughly) inspected, cleaned and graded. Mechanical vectors are passive carriers, which are not needed for the propagation of the species being carried.

Bivalve shells are a target of shell boring polychaetes, such as *Polydora ciliata* inhabiting the shell of blue mussels, oysters, scallops and clams. This polychaete weakens shell strength (Kent 1981), increases energy requirements, impairs the overall health of the bivalve (Kent 1979, Ambariyanto & Seed 1991), and harms in particular the mantle tissues mainly responsible for reproduction in mussels (Wachter, 1979), thus is classified as harmful to the host at least at high infestation rates (Michaelis 1978). A weakening in shell strength, the increased energy demand, the decline of reproductivity, and on occasions increased mortality, can severely impact both wild and cultivated mollusc populations.

Other macro parasites inhabit organs and tissues of bivalvess' softbody. From the German Bight for example, from two (affecting *Crassostrea gigas*) to ten (affecting *Mytilus edulis*) different macro parasite species are reported to be common (Thieltges 2006). They belong to different phyla, inhabit various tissues and organs and cause a variety of symptoms. The intensity of the infestations can vary according to the conditions of the habitat. Blue mussels show the highest infestation rates at intertidal areas, followed by subtidal and offshore areas (Buck *et al.* 2005, Brenner *et al.* 2009). Other areas within the distributional range of blue mussels (*M. edulis*) and close relatives (*Mytilus galloprovincialis, Mytilus trossulus*) show comparable numbers of parasite species, however, a shift in the species spectrum. Some species are extensively found within the distributional range whereas others are restricted to relatively small areas. Thus, a movement of infested mussels amongst different areas and habitats to uninfected areas may support the transfer of parasites and pests between tidal levels e.g. from intertidal to subtidal areas, or from areas with high parasite diversity to areas showing a limited spectrum of species. The role and effects of macro parasites on the health status of their hosts are still debated intensively. For *Mytilicola* species, including *Mytilicola intestinalis and Mytilicola orientalis,* the characteristics range from being a pest with severe negative impacts (Odlaug 1946, Meyer & Mann 1950, Dethlefsen 1975), to only being a commensal organism feeding on unutilized fractions of the mussel's gut (Calvo-Ugarteburu & McQuaid 1998). Descriptions of other common parasitic species are more consistent; i.e. Metacercariae of trematodes found in the digestive gland of blue mussels are described as reducing growth (Taskinen 1998, Calvo-Ugarteburu & McQuaid 1998), general health (Calvo-Ugarteburu & McQuaid 1998), reproductive ability (Coustau *et al.* 1993), and hamper feeding (Thieltges 2006) of the mussel.

Independent of the final evaluation of the resulting health effects of different parasite species, spreading of these species should be avoided, whether by statute or industry voluntary codes of practice. Since some parasites impact commercial marketability by reducing shell or affecting meat appearance and integrity (*P. ciliata*), cause aesthetic problems due to their colour, size and can reduce the value of mussels by decreasing meat yield in the case of *M. intestinalis* and provoking distaste in *Pinnotheris spp*. Under current EU health legislation e.g. EC Directive 2006/88, *Urosalpinx cinerea*, *Credipula fornicata* or *Mytilicola* sps are not listed pests, although they are recognized as serious pests among certain member states, as in France, Brittany (Grall & Hall-Spencer 2003) and Spain, Galician Rías (Sánchez Mata & Blanchard 1997) for *Crepidula fornicata*. Thus, unless consignments are refused entry by farmers of commercial ground, consignments of infested bivalves can be relayed within and between member states and third countries, uncontrolled. There has been progress between the UK and Ireland to increase the level of inspection to attempt to control this movement.

5.5.3 Transfer of biotoxins, cysts, larvae and eggs

The main food source for bivalves is phytoplankton and thus the potential for accumulating algal toxins is high. Several human diseases have been reported to be associated with many toxin-producing species of dinoflagellates, diatoms, nanoflagellates and cyanobacteria that occur in the marine environment (CDC 1997). Marine algal toxins become a problem primarily because they may concentrate in shellfish and fish that are subsequently eaten by humans (CDR 1991, Lehane 2000), causing severe syndromes of poisoning (e.g. ASP, DSP, PSP) and, on occasion, death. In addition to accumulating poisons, filtering bivalves can function as a vector for the distribution of reproductive cysts of toxin-producing algal species. These cysts may survive in unfavourable conditions for years buried in the sediments (Tillmann & Rick 2003) and can, after being re-suspended and translocated in e.g. the intervalval water of molluscs, build up new populations in formerly unaffected areas (Mons *et al.* 1998). Thus, may result in human health risks, fishery and culture closures and commercial losses. The transportation of toxin-producing algal species and their resting cysts (McMinn *et al.* 1997), either in a ship's ballast water or through the movement of shellfish stocks from one area to another, provides a possible explanation for the increasing trend of harmful algal blooms (Hallegraeff *et al.* 1995). In many cases of introductions and transfers of bivalve molluscs for cultivation, no serious attempt has been made to avoid unwanted organisms. The export of half- grown Pacific oysters, *C. gigas*, spat from France to Ireland in 1993 is an outstanding example. Examination after arrival of the oysters, which had been certified "free from other species", revealed numerous other species: Several fouling organisms, other bivalve species (which may potentially carry pathogens or parasites) and 67 species of phytoplankton, including dinoflagellate cysts (O'Mahony, 1993; Minchin *et al.*, 1993). Most of these accompanying organisms would disappear or have no or minor effects on cultivated species in their new environment. However, sometimes new species may cause permanent or long-lasting fouling problems, competition for space or food, or in extreme cases – disease. While fouling macro-organisms may be relatively easy to find and identify if in appropriate numbers, microorganisms will be more troublesome. Through feeding, bivalves will filter an unknown variety of protozoa, bacteria and viruses.

The high diversity of species living as commensals on the shells of bivalves compares well with the number of species present in their intervalval fluid. Many species from different phyla such as bacteria, viruses, fungi, or ciliophora use bivalves as a host, whereas others (or other species from the same mentioned phyla) are filtered actively as food (e.g. micro algae) or enter the molluscs accidently through the incurrent water flow. Depending only on the size of organism many species and especially their larval stages, cysts or eggs can be present in bivalves. Since live bivalves are usually translocated dry, trapped species can travel together with their temporary host over large distances. For example, egg capsules of the American oyster drill, *Urosalpinx cinerea*, have been found in the Oosterschelde, an area of shellfish culture in The Netherlands. Most probably *U. cinerea* was introduced with transferred shellfish from south-east England (ICES WGITMO 2008).

As part of the controls to protect public health, EC Regulation 854/2004 requires a monitoring programme of shellfish relaying and production areas to be established to check for the possible presence of toxin producing plankton in the water and biotoxins in the shellfish flesh in place????

5.5.4 Transfer of micro parasites and diseases

The effects of transfers and introductions of bivalve molluscs are to some extent unpredictable. Moving molluscs, there is a risk of introducing pathogenic agents or of disturbing the balance between potentially pathogenic agents and host species in the recipient ecosystem. Risk is not eliminated by merely following official regulations.

To minimise the risk of unwanted effects, considerations are normally done prior to introductions and transfers. Both the ICES Codes of Practice, EC regulations, The Animal Health Code from Office International des Epizooties, and common veterinary practice are designed in order to assess risk, and avoid introductions of pathogenic agents and exotic species with the consignments. Even if all guidelines and recommendations are followed, it is impossible to predict all possible effects of transfers and introductions, and to predict which disease problems may follow. The spread of pathogens frequently occurs ahead of the diagnostics. Learning from introductions and transfers of other bivalve species is therefore essential, to enable a proper risk assessment.

In addition to macro parasites, molluscs or bivalves are both host and vector of micro parasites, e.g. *Marteilia*, *Bonamia, Microcytos* and *Perkinsus* species. As these parasites severely affect the health of host shellfish, in contrast to macro parasites, they are listed under the mandate of the World Organisation of Animal Health (OIE, 2010) and current shellfish health legislation (EC/2006/88). Prior to transfer activities, organisms must be declared free of these listed diseases when destined for an area of equal or greater health status. A transfer of animals infected by a listed disease is generally forbidden to areas recognised free of that disease. For decades, outbreaks of e.g. Bonamiasis and Marteiliosis have led to dramatic losses in the French oyster industry and a simple inspection for listed pathogens prior to transfer is not guaranteed to prevent the introduction, spread or containment of disease. Consignments should originate from an area of known health status and be subject to surveillance testing under current legislation to establish a known helath status prior to movement and deposit.

Marteilia refringens, was present in some unknown intermediate host or stage in the environment on the French oyster beds. While flat oysters, *Ostrea edulis*, could be kept free from *Marteilia* in tanks using water from the oyster beds, oysters once moved out on the beds became infected (Mortensen, 2006). This example illustrates that there is a lack of knowledge on the life cycles of even the best known bivalve pathogenic agents. *Marteilia refringens* seem to go through several stages in a complex life cycle (Grizel *et al.*, 1974; Perkins, 1976). Concerning the *Marteilia* sp. documented from the Calico scallop *Argopecten gibbus* from the coast of Florida (Moyer *et al.*, 1993), knowledge is more scarce. Thus, we do not know which scallop, or other bivalve species, may be susceptible, which species might be vectors, in which stage the parasite may be dispersed, or which species might be intermediate hosts. The most serious oyster pest in Europe, the protozoan *Bonamia ostreae* also illustrates the problem. At first sight it seems not to have a complicated life cycle like *Marteilia*. *Bonamia* propagates by binary fission until the host cell, the oyster haemocyte, bursts. But despite a number of studies, there remain unanswered questions. It is not known why small oysters are unaffected, but die due to the parasite when they approach sexual maturity. A life cycle with a phase in the ovarian cycle has been suggested (van Banning, 1990), but it is still not fully understood. The search for intermediate hosts for *Bonamia ostrea* is part of the EU project OYSTERECOVER (oysterecover.eu). Also, the host range of many agents is largely unknown, and extensive studies are necessary in order to identify possible host species. There is a tendency to link the pathogenic agents to the species in which they are first described, but this may often be wrong. When the protozoan *Microcytos mackini* was identified as the causative agent of Denman Island Disease of Pacific oysters, *C. gigas* in British Columbia, Canada, the agent was first linked to this oyster species, but then similar organisms were observed also in flat oysters, *O. edulis*, and Olympia oysters, *O. lurida*, in the US, and Sydney rock oysters, *Saccostrea commercialis*, in Australia. The causative agents were identified as two different *Microcytos* species (Farley *et al.*, 1988). Later experiments showed that *M. mackini* was pathogenic also for the oysters *Crassostrea virginica, Ostrea edulis* and *Ostreola conchaphila (Ostrea lurida)* (Bower *et al.*, 1997). The example illustrates that what may seem as one disease in one species may appear in different areas, and be caused by different, but related parasites, which themselves may be pathogenic for different host species. This complicates the one disease-one host-one area management approach, which is commonly applied. Even when we have documented that a specific agent is actually pathogenic, there are often great uncertainties concerning the infectious dose of agents, influence of environmental factors on disease, etc.

In the 1960s, *Crassostrea gigas*, was deliberately introduced from Japan to France and since too much of the coastal regions of Europe. It was seen as a disease free, good growing alternative to *Ostrea edulis* and *C. angulata* whose stocks suffered severely under *Bonamia* and *Marteila* infections. The Pacific oyster is scientifically proven non-susceptible to *Bonamia* and so movements were routinely made around Europe with little control. In the 1990s a movement of *C. gigas* was made to Ireland from France under (EC) 91/67. The introduction was made and deposited in the sea, prior to inspection for susceptible or hitch hiker species. After the event, non-indigenous species and indigenous species capable of transmitting serious disease were found; including the pest *Mytilicola orientalis,* and *Ostrea edulis* which is capable of transmitting *Bonamia* (Minchin 1996). In a more recent example the Oyster Herpes Virus (OHV-1), which is regarded to be present in most French oyster hatcheries growing Pacific oysters, was moved routinely for years around France and further afield uncontrolled, with little attention to inspection for the presence of hitch hikers. Anecdotal evidence suggests such practices continue. Lately, an extremely pathogenic variant of OHV, OsHV-1 μvar was identified the causative agent of high mortality in France, Ireland and the Channel Island of Jersey, which prompted the EC Commission to consider the variant as an emerging disease. As a result Commission Regulation 175/2010 was introduced to apply control measures on the prevention and control of OsHV-1 μvar and measures beyond 2010 have been agreed under article 43 of 2006/88/EC.

Viruses can be surprisingly inert. After the finding of the fish pathogenic infectious pancreatic necrosis virus (IPNV) in scallops, *P. maximus* (Mortensen *et al.*, 1990), the subsequent study of the fate of IPNV in scallops (Mortensen *et al.*, 1992; Mortensen, 1993) showed that the virus was taken up during filtration, persisted for long periods of time, and was shed into the water by contaminated scallops. No viral propagation was found, and in nature, the virus excreted from contaminated bivalves would rapidly be diluted in seawater. Scallops and other bivalves should probably still be considered potential vectors of fish pathogenic viruses.

The risk of disease transmission becomes greater when there are true biological vectors, where a pathogenic agent maintains its normal function and even propagates. Considering the above-mentioned coexistence between any animal and its microorganisms, the microecological balance may be disturbed during an introduction or transfer. From the introduced scallop's point of view (Mortensen, 2000), there may be unknown reservoirs, intermediate or alternative hosts of pathogenic agents in its "new" environment. From the point of view of the inhabitant of the recipient environment, the "newcomer" may pose a threat, bringing new microorganisms, which are potentially pathogenic agents for them.

One example is the virus causing gill disease which eradicated the susceptible populations of Portuguese oyster, *Crassostrea angulata*, from the French coast, while the resistant Pacific oyster, *C. gigas* remained only slightly affected by the disease (Comps *et al.*, 1976; Comps, 1988). It has been hypothesised that the Pacific oyster, which was actually introduced to France just before the first outbreaks, was actually the vector, being adapted to the virus through generations of coexistence in Japan. There is the also possibility that *Crassostrea virginica*, the American oyster may be introduced to Europe to complement/replace Pacific oyster cultivation. It is a species susceptible to serious the exotic disease listed under 2006/88/EEC, *Perkinsus marinus;* and also the non-listed *Haplosporidium nelsoni*. These diseases would be a serious threat to Pacific Oyster and clam stocks. The best preventative measure would be to prevent the introduction of *Virginica* into European waters.

5.5.5 Transfer of human pathogenic agents bacteria and viruses

The survival of bacteria in seawater and their presence in bivalves varies with exposure to environmental factors such as temperature, salinity and the present of organic debris and it is influenced on seasonal and spatial scales (Hernroth 2003). The bivalves' response towards ingested microbes is to eliminate them. However, it has been shown that *Salmonella typhimurium* can survive more than two weeks after being injected into the circulating system of mussels (Hernroth 2003). *Salmonella* species can cause enterocolitis, enteric such as typhoid fever, and septicemia with metastatic infections in humans. Seawater is the natural habitat of the *Vibrio* bacteria, feared as pathogens in fish and shellfish (Shao 2001). *Vibrio* can also cause severe infections in humans after consumption of raw or undercooked shellfish and contaminated food. A special hazard is caused by *V. vulnificus,* where severe infections can occur through skin lesions (Blake *et al.* 1979).

Like bacteria, viruses are predominantly concentrated in the digestive glands, but can also be absorbed through the gills (Abad *et al.* 1997) of bivalves. Certain viruses such as the Norovirus are even more persistent and can remain infectious for weeks to months in seawater or in sediment (Gantzer *et al.* 1998). Although they are inherently unable to multiply in bivalves, shellfish are efficient vehicles for transmission of pathogenic viruses to humans. Epidemiological studies have revealed that human enteric viruses are the most common pathogens transmitted by consumption of bivalve shellfish (Lees 2000, Lipp & Rose 1997). Among these, HAV is the most serious viral infection linked to the consumption of bivalves. In Italy, recent estimates suggest that approximately 70 % of HAV cases are caused by shellfish consumption (Salamina & D' Argenio 1998). The relatively long incubation period following initial infection (average 4 weeks), complicates the traceability of the viral source. Thus, HAV infections caused through shellfish consumption are probably underreported or even remain undiscovered. Norovirus and serotypes of the adenovirus group are associated with gastroenteritis. These viruses have been recorded in seawater and shellfish in many countries (Formica-Cruz *et al.* 2002). In particular overall viral infections caused by the Norovirus (gene group II) have shown a remarkable increase, as registered by the Robert-Koch Institute (RKI 2000). This increase however, may be because Norovirus infections must be reported by law. However, the rapid course of the illness within a few hours complicates appropriate countermeasures.

Recently when checking guidelines on introduction of *Crassostrea gigas* (gigas) spat to Scotland from Jersey in the Channel Islands for ongrowing, current legislation (guidance under EC Directive 91/67 and the Wildlife &Countryside Act) allows the movement to an approved zone; following screening for signs of ill health, pathology or the presence of hitch hiker species, evident by visual inspection. Fish health legislation considers listed pathogens and susceptible species but no clear guidance on emerging disease or infectivity by pests or parasites not obvious during inspection, and in the absence of abnormal mortality. Shellfish being moved from a country infected with a non-listed pathogen may have developed immunity to pathogens with the potential to transmit the pathogen to naïve populations; having a long term detrimental effect on multiyear classes in the area of destination and beyond. The *C. gigas* introduced from Jersey to Scotland originated from a French hatchery under proper certification, however the majority of (if not all) French hatcheries are suspected to be infected with Oyster Herpes Virus (OHV) and *Vibrio* sps such as *V. splendidus*, pathogens found naturally in the aquatic environment, and closely associated with summer mortality in *Crassostrea gigas*; causing high mortality and affecting all year classes of oysters in many areas of France. These recent introductions of *C. gigas* from France via Jersey could potentially have a long term detrimental effect on naïve cultivated *C. gigas* in Scotland, Ireland and elsewhere; however current legislation allows such movements, allowing free trade at the expense of a precautionary approach.

5.5.6 Genetic effects of transfers

It is becoming increasingly important to identify species transferred or introduced, not simply morphologically but using appropriate statistically significant screening, including specific and sensitive molecular tests. It is also recognised that the gene pool of broodstocks used to provide progeny for cultivation or augmentation of wild should not act as vectors, of disease, compromise or reduce genetic integrity of indigenous populations, result in interbreeding, compromise reproduction or introduce traits not conducive to growth and survival.. To predict the genetic consequences of transfers, information on genetic composition of species to allow their identification and differences between source and recipient populations is vital (Beaumont 2000). This may be expressed by morphological, allozyme and DNA based data on genetic differentiation of populations and sub-species. Other considerations are the numbers of individuals transferred and whether they are wild stock or a hatchery product. Loss of genetic diversity is difficult to avoid in hatchery conditions although there are also ecological advantages to using disease-free or sterile hatchery seed. Examples are given on how mitochondrial DNA data indicating significant genetic consequences of the introduction of *Argopecten irradians* from the USA to China, and on *Patinopecten yessoensis* introduced from Japan to Canada. Beaumont (2000) recommends that potential risks and consequences of hybridisation should be experimentally assessed before introductions of scallops are carried out. Hybridisation is unpredictable and can lead to loss of genetic diversity or the breakdown of co-adapted gene complexes, resulting in a poor commercial product. The use of sterile triploid scallops for introductions to avoid hybridisation and reduce ecological impact has merit but reversal to diploidy may occur. There is also the risk that introductions breeding with indigenous stock could result in reduced future fecundity.

The Pacific oyster (*Crassostrea gigas*) was introduced in Europe as an alternative to the Portugese oyster following the viral disease that crashed the Portuguese oyster (*Crassostrea angulata*) population. Currently there is contact between the species in two areas of the world, between France and the south of Portugal and between Japan and Taiwan. In these regions hybrids have been found. This hybridisation has its impact on the *C. angulata* population in Southern Europe. Pacific oyster spat is mainly obtained from captures but about 20 % of pacific oyster spat is derived from hatcheries. Hatcheries mainly produce triploid spat, which is not considered as a safe genetic confinement tool as triploids occasionally breed. The effect of the partial sterility of triploids is poorly known, although expertise exist on the risk, e.g. biovigilance survey program in France. Another threat to wild populations is the use of tetraploid broodstock if they escape from quarantine, as their fitness relative to diploids and the impact of their breeding with diploids is still unknown (GENIMPACT 2007). Another impact has recently been recognised resulting from the reproduction and spread of Pacific oysters in the wild, invading ecosystems to replace indigenous species and causing a problem to shellfish farmers because of extensive wild and uncontrolled spatfall. This non-indigenous species which was originally introduced to enhance and expand aquaculture production has become established in many European countries to the extent of now being considered a pest, not only to farmers and wild fisheries, but impacting on leisure industries by impacting on beaches and pier areas.

The European flat oyster (*Ostrea edulis*) occurs naturally from Norway to Morocco in the North-Eastern Atlantic and in the whole Mediterranean basin. The species was also introduced in the United States, from Maine to Rhode Island (1930s and 1940s) and in Canada (about 30 years ago). Mediterranean flat oysters have more genetic variability than the Atlantic population. The North American populations were derived from the Atlantic population. Most flat oysters are grown from wild captured seed but e.g. in the UK and Ireland hatcheries are producing flat oyster spat. Hatchery cultured spat can result in a reduced genetic variability, if care is not taken in selecting broodstock, resulting in reduced variability of the natural populations. Polyploid flat oysters could be produced but are currently not farmed. No large selective breeding programmes has been initiated for *O. edulis*, however some experiments to improve resistance to *Bonamia ostreae* have been carried out. Results show a higher survival rate and a lower prevalence of this parasite in selected stocks but also a reduced genetic variability in mass selected populations (Lapègue *et al.* 2006).

The mussel species *Mytilus edulis* and *Mytilus galloprovincialis* have a huge overlap in distribution from France to Scotland. *Mytilus edulis* is found to be homogeneous throughout its range while *M. galloprovincialis* is genetically subdivided into a Mediterranean and an Atlantic group. *Mytilus trossulus* also exists in discrete areas. In places where two or more of these species occur together, hybrids are found and information on the distributions of mussel species and their hybrids is gradually improving (Dias *et al.* 2008a; 2008b). Without this basic information it is impossible to estimate the genetic influence of mussel aquaculture on wild populations (Beaumont 2000).

The blue mussel *Mytilus edulis* is the indigenous and dominant species of mussel in Scotland, and production was until recently thought to consist exclusively of this species. However, blue mussels are now recognised as including three distinct species (*M. edulis*, *M. galloprovincialis* and *M. trossulus*). The three species are able to interbreed and produce hybrids which potentially could be fertile. Coupled with the potential influence of environmental conditions on growth and shell morphology, this makes it difficult to distinguish the species and their hybrids based on shell shape alone. Recent research on the distribution of the *Mytilus* species in Europe has been greatly facilitated by molecular tools which, based on the animal's DNA, are able to reliably distinguish between species and hybrids in both wild and cultivated populations (Dias *et al.* 2008b). The identification of *M. galloprovincialis* in cultivation areas has raised questions relating to the risks associated with transfer of seed and consequentially sustainability of blue mussel cultivation in certain countries. Recent reports by Scottish growers, focussed in a single sea loch system, of fragile-shelled *M .trossulus* which would break during grading. Forensic investigation of the occurrence of *M. trossulus* in a few sea lochs in Scotland indicates that the distribution of *M. trossulus* appears to be consistent with the species having been moved from place to place during transfers of mussel stock for cultivation purposes. Where *M. trossulus* has been moved out with the original Scottish site to areas of full strength salinity seawater, *M. trossulus* have reportedly died and not spread through natural settlement. It has not yet been found in wild populations, even where adjacent cultivation ropes contain large proportions of *M. trossulus*. The majority of mussel production sites in Scotland produce *M. edulis* and work is ongoing to systematically manage out *M. trossulus* from the Scottish index site to minimise any risk of its spread within Scottish waters. Further, the three main cultivation methods for mussels (bottom culture, suspended culture and pole culture (bouchot method)) have their own specific growth requirement. Therefore, there may be a genetic impact due to genotype-specific mortality in areas where aquaculture is the major source of mussel biomass.

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Scallop spat is obtained from wild-captures and from hatcheries. Hatchery scallops can easily escape from farms, but as scallop aquaculture in Europe is done on a very small scale (213 tonnes in 2004 while the landings of captured fisheries exceeded 50 000 tonnes), the genetic effect on wild populations is probably not considered significant (Beaumont 2000), as is the risk of genetic impact from the blue mussel hatcheries in Europe which remains negligible owing to current low production.

5.5.7 Impact of transfer on biodiversity

Many non-native species introductions have not been registered and may have had no impact on the receiving environments (Gollash 2004). However, up to 21 introductions into the marine environment have been classified as invasive (Kettunen 2009). The impacts identified have been wide ranging and include impacts on native habitats and species. More specifically, it has been documented that species can have direct impacts by excluding native species and thereby reducing biodiversity. The introduction and transfer of marine molluscs from fisheries and aquaculture includes the risk of transporting competitors, predators, parasites, pests and diseases which have compromised intended molluscan culture and wild fisheries.

Introductions as well as transfers, in the course of normal trade, particularly of half-grown oysters, have been responsible for the establishment of several harmful and nuisance non-native species. Once established at a new locality these may continue to be moved by various means or by natural expansions of their range. *Crassostrea gigas* was introduced to Ireland from France, under 91/67 EC (a species recognized as being non-susceptible to *Bonamia* (*O. edulis* is susceptible)), the deposit was made and after the event non indigenous species and indigenous species capable of transmitting serious disease were found; including the pest *Mytilicola orientalis,* and *Ostrea edulis* which is capable of transmitting *Bonamia*. (Minchin, 1996; Minchin, 1998).

The expansion of the Pacific oyster, *Crassostrea gigas*, throughout northern latitudes of Europe has been well documented (Reise 1998; Drinkwaard 1999; Smaal *et al.* 2005). The spread has been rapid and has resulted in very high recruitment of the oysters in marine habitats. In some areas the diversity of species associated with *Crassostrea gigas* have been demonstrated to be higher than that of ambient habitats (mussel beds; Kochman *et al.* 2008). While species diversity may be comparable or higher on short spatial scales, the invasive nature of *Crassostrea gigas* is such that habitat heterogeneity is greatly reduced over large spatial scales. There is the additional risk of transfer of the highly pathogenic oyster herpes virus variant, OsHV-1 uvar, with the potential of causing high mortality in naïve wild and cultivated populations of *Crassostrea gigas.*

Ruditapes philippinarum (Manila clam), originated from Asia, was introduced into France in the 1980s for aquaculture purposes, it was introduced into Arcachon Bay in 1980. For economic reasons, this aquaculture was unsuccessful and was rapidly abandoned. Subsequently the remaining species found good natural conditions to reproduce and expanded in the wild. Ten years later, this exotic clam species was more abundant than the native one, *Ruditapes decussatus*. This situation is explained by superior recruitment and rapid growth to outperform the indigenous species. Since 1992, the biomass of *R. philippinarum* has been exploited by fishermen (Dang *et al*., 2010). What is uncertain is how the Manila clam outcompetes the indigenous species and contributes to the modification of biodiversity in the bay. Both species colonize the same habitat and with time, the ratio between the 2 species was modified to the benefit of the Manila clam. The competition is probably not direct for space and food but associated with the fishing activity. The stock exploitation impacts more drastically the European species because of it low capacity to recolonize the habitat compare to those of the indigenous species (Auby *et al.*, 1995).

Historically, slipper limpets were introduced to England, carpeting areas of the foreshore, replacing the natural fauna there. Despite its impact no controls were sought and it quickly became established, destroying ecosystems. Under current EU health legislation, pests such as *Urosalpinx cinerea*, *Crepidula fornicata* and *Mytilicola* spp. are not listed, although they are recognized as serious pests within certain member states but not controlled. Such species can be relayed with host aquaculture shellfish within and between member states and third countries, uncontrolled.

5.6 Scientific tools to support policy decisions on cultured shellfish transfer issues

5.6.1 Risk assessments

A number of EU initiatives have documented the impacts of alien species on ecosystems and while these projects consider impacts of introductions in all habitat types, there is considerable focus upon marine habitats. For example the DIPNET project (http://www.revistaaquatic.com/DIPNET/) specifically provided a full review of disease interactions and pathogen exchange between farmed and wild finfish and shellfish in Europe (Workpackage 1, Deliverable 1.5). The project also has provided a review on the application of Risk assessment and predictive modeling in relation to aquatic animal health management. The importance of consequence assessment – which measures the impact of pathogen exchange and disease interaction between wild and farmed aquatic animal populations has been highlighted as an issue of concern

The IMPASSE EU project (http://www2.hull.ac.uk/discover/hifi/impasse.aspx) is another comprehensive review of interactions between alien species and the environment. Similarly it provides a number of worked examples of risk models to assess interactions between introduced species and the receiving environment and has provided a comprehensive literature database on this subject.

Forrest *et al.* (2009) reviewed literature on cultivation impacts of Pacific oyster, *Crassostrea gigas* farming in estuaries and used a risk ranking method to evaluate ecological risks (and associated uncertainty intervals) for each of the issues associated with estuarine oyster culture. Based on subjective assessment of the likelihood and consequences (severity, spatial extent and duration) of adverse effects. Their assessment reveals that the introduction and spread of pest species are potentially important but often overlooked consequences of oyster cultivation. By comparison with most other sources of impact, the spread of pests by aquaculture activities can occur at regional scales, potentially leading to ecologically significant and irreversible changes to coastal ecosystems. They suggest that future studies of cultivation effects redress the balance of effort by focusing more on these significant issues and less on the effects of biodeposition in isolation. Furthermore, the acceptability of aquaculture operations or new developments should recognize the full range of effects, since adverse impacts may be compensated to some extent by the nominally 'positive' effects of cultivation (e.g. habitat creation), or may be reduced by appropriate planning and management. Even more broadly, aquaculture developments should be considered in relation to other sources of environmental risk and cumulative impacts to estuarine systems at bay-wide or regional scales, so that the effects of cultivation are placed in context.

In the UK, recent guidance provided by the Alien Species Group on behalf of the United Kingdom Technical Advisory Group (UK TAG) outlines the background to how alien species are dealt with in relation to achievement of the Water framework Directive's (WFD) environmental objectives (http://www.wfduk.org/). If a red list alien species such as *Crassostrea gigas* is found in a water body it will then have to be proved it is having more than a "slight adverse impact" and this will be carried out using monitoring results or risk assessment. If it is having more than a slight adverse impact then the water will be classified as moderate or worse and if not then the water will be classified as good. The question of how this will then affect the shellfish farmers is important as they are growing *C.gigas* legally under licence (and were encouraged to do so in the past) and they have little control of "wild" settlement outside their farm. If therefore the presence of *C.gigas* is deemed to downgrade the classification of the water body it should be clear what effect will this have on shellfish farming in the area. Natural England is considering production of a document outlining the reasons for leaving *C. gigas* on the red list as there was some disagreement as to whether there was scientific evidence to support it being on the list.

Risk assessment methodologies have been developed for a range of scenarios, disease, non-native species, methodological innovation. These risk assessment need to be standardised, updated and applied. In addition, they need to be available to industry, to minimize the impact of transfers and to prevent the introduction of invasive species, contingencies to minimize their impact and plans to eradicate introductions.

5.6.2 Epidemiology and models of propagation of invasive species

Impact of pathogens, after unexpected introduction in a bay, depends mainly on ecology of the pathogen, propagation conditions, and also defences and resistance of the host. The spread of the pathogen is linked to the hydrodynamics. It is becoming increasingly possible to initiate field epidemiology, with some basic knowledge on emission of pathogen organisms, their survival and transport in open sea, and their ability to infest local bivalves (Des Clers, 1991; Ford *et al.*, 1999). This simulation is further complicated when intermediary hosts exist. The same type of methodology might apply to invasive species, with supplemental considerations about survival conditions of adults or larvae, reproduction capability, dispersion stage in the life cycle, settlement behaviour.

More knowledge on understanding the behaviour of populations of invasive species; modelling population expansion and factors governing the species proliferation; addressing factors (e.g. climate change) that facilitate range expansions or proliferation is needed.

5.6.3 Surveillance and Biosecurity Measures

Health Surveillance involves strategies and procedures to systematically look for early signs (detect) and assess the adverse effects on the health/status of a country. The priority should be prevention and to establish the absence of a problem, but have the facility to detect one if it exists. Therefore it is necessary to develop a plan to evaluate and establish the status of a country and be able to control a problem if it occurs, e.g. via surveillance and eradication if a disease or invasive organism is found. This may be undertaken by voluntary industry codes of practice or by statute, depending on the status of each country and what it aims to control.

It is essential to identify the risks associated with aquaculture production and to introduce methods to minimise and control them. These may be associated with the introduction of disease, pests, parasites, fouling organisms or adverse effects associated with movements or transfers of bivalve shellfish, equipment and sea water associated with the transfers.

The requirements, legal or otherwise, depend on their value; the impact on sustainability and whether controls are considered to be possible. Measures should be in place to measure their success and to point to further steps, if deemed necessary. It is vital to involve industry, policy makers and scientists in the development of all strategies and procedures to ensure that each embrace them and contribute effectively to their success.

In the development of a new Animal Health Law (SANCO/7221/2010 working document) regarding movements of animals for trade and measures for disease control, the conclusions of the chief veterinary officers emphasise the importance of surveillance as a key element of animal health policy. They give priority to preventive approaches, early detection and quick response; notification which in turn enables timely control and eradication when feasible. Also, clear objectives of such a system should be established to generate and manage reliable, transparent and accessible epidemiological & surveillance data connected into an appropriate information system.

Risk-based animal health surveillance under Council Directive 2006/88/EC is designed to prevent and control certain diseases in aquatic animals aquaculture animals and products; including measures on suspicion of, or during an outbreak of disease. Member States must ensure that a risk-based animal health surveillance scheme is applied in all farms and mollusc farming areas and the aim of the schemes is to identify and mitigate risks, instigate good site biosecurity measures, to detect any increased mortality and the presence of listed or emerging diseases- where susceptible species are present. Part B of Annex III considers surveillance inspections on sites, surveillance and frequency being dependent on member's health status and risk level combined with their adherence to the site biosecurity measures plan. Passive and intelligence led surveillance together with training awareness, in providing advice to operators on aquatic animal health issues play an essential part to the success of such models.

Frequency of inspections are determined by two factors: the health status of the Member State regarding diseases; and the risk level of the farm or mollusc farming area in relation to the contracting and spreading of diseases. The health Status differentiates between Categories I-V: disease-free; not free but subject to a surveillance programme; not known to be infected but not subject to surveillance programme; infected but subject to an eradication programme; Known to be infected, subject to minimum control measures.

Risk factors to be taken into account when determining the risk level of farms and mollusc farming areas are divided into; high, medium or low risk levels, and include:

- direct spread of disease via water;
- movements of aquaculture animals;
- type of production;
- species kept;
- bio-security system, staff competence and training;
- density of farms and processing establishments in the area;
- proximity of farms and mollusc farming areas having lower health status to the farm or mollusc farming;
- area concerned;
- health status track record of farms in the area;
- presence of disease pathogens in wild aquatic animals;
- risk posed by human activity, predators or birds.

The use of a complex system is to be considered to assess risks, allowing classification of farms to their risk level. Farms and mollusc farming areas will have different levels of risks, according to their risk level which will differentiate biosecurity measures required on site and the level of surveillance and inspection required; taking into account the need to optimise the use of resources.

Types of surveillance include:

- PASSIVE- prompting investigation including sampling, controls, surveillance & epizootic investigation
- ACTIVE- routine inspection, examination of stock, diagnostic sampling on suspicion/increased mortality
- TARGETED- routine inspection, prescribed sampling by specified methods

There is mandatory immediate notification of the occurrence or suspicion of specified disease, or any increased mortality, prompting investigation.

Biosecurity measures plans (BMPs) on shellfish Aquaculture Production Businesses (APBs)

Movement of live shellfish within the EC community and from elsewhere is now routine, increasing the risk of introducing and spreading disease. Good husbandry, hygiene and biosecure practice can minimise this risks and it is now a part of statute within the EU member states, for all APBs must have a plan associated with authorisation. Farmers need to consider legislation and codes of practice appropriate to them, their application, risks, their mitigation and to develop a practical plan appropriate to them, i.e. good hygiene practice as relevant for the activity concerned to prevent the introduction and spreading of diseases.

An example of a practical plan for shellfish farmers, with minimum information to be included in it, is found at http://assg.org.uk/#/conf-papers-10/4535236015. 
The presentation also includes advice on hygiene, biosecurity and good husbandry practices, risks factors and their mitigation, plus the role of the fish health inspector.

Good husbandry and biosecurity practices are essential to successful prevention and control of disease.

5.7 Recommendations to farmers and policy makers

5.7.1 Recommendations to farmers

- To conform to industry codes of practice and legislation; e.g. ensure that illegal transfers are not made and that certification procedures are kept;
- To develop and maintain a biosecurity measures plan;
- To improve record keeping and make records available to official health experts;
- To employ best management practices of husbandry and hygiene to maximise health, growth and site production, with minimum impact on neighbouring sites.

Industry is sometimes so focused on the economic return from shellfish aquaculture that concerns/precautions about surrounding biological issues of transfers of shellfish from one area to another can be overlooked or ignored. Such an oversight can potentially impact the farming operations or marketing of large numbers of growers if disease introductions are done through illegal transfers of non-disease certified shellfish from area to area, state to state, or country to country. While these may seem innocent enough to the non-informed grower, there are far reaching biosecurity issues which surround these illegal activities. A message to impart is that good husbandry and biosecurity practices are essential to successful prevention and control of pests, parasites, fouling organisms and disease, with associated benefits in production and profit.

Record keeping of farming activities are integral in some shellfish culture businesses, but in others, they may be non-existent. Growers should have some kind of personal recordkeeping documentation of inputs, transfers and outputs of their operation. If tainted shellfish are found in the marketplace or if a new disease, predator species, or non-indigenous species shows up in a new place, good data about seed or adult shellfish can help to solve transmission problems. The same could be said for shellfish moved to a grower's site which may have come from less than approved waters and end up in the market, only to cause sickness for consumers and have a strong negative impact on shellfish sales.

This recordkeeping and data collection can be supplemented by the keeping of environmental data (wind, weather, water temperature, salinity, dissolved oxygen) which can assist the grower in understanding how his crop is progressing, or not. All of this should be part of a Code of Practice that industry could voluntarily adopt to acknowledge that he is operating in an environmentally sound way. This would be a good protection against biosecurity issues with far reaching economic and biological implications.

Industry should also be completely aware that biosecurity infractions will be handled in strict fashion by enforcement agencies, and if in violation of legislation or regulation will be prosecuted to the full extent of the law. In addition, other growers who knowingly ignore illegal activities by other growers should completely understand that their silence ultimately makes them compliant with the illegal activity, and subjects their businesses to harm if not reported to the appropriate law enforcement agency.

5.7.2 Recommendations to policy makers

- Harmonise legislation: to ensure that existing and developing legislation is joined up in relation to its interpretation, understanding and implementation by all stakeholders;
- Improve dialogue with industry improve communication amongst farmers, scientists and policy makers, e.g. by forum meetings;
- Apply enforcement more effectively; develop policy;
- Best educate and implement biosecurity measures with industry, and scientists;
- Develop and maintain a trusting open dialogue with industry;
- Coordinate and develop legislation to maintain sustainability.

Explaining the scientific implications of ignoring illegal introductions, transfers of shellfish from non-approved waters, or by-passing any regulatory protocol could have significant negative effects for growers not only in the local area, but throughout regions or countries. Understanding the economic implications, from both sides of the illegal activity, can be most beneficial over time for both industry and policy makers.

Harmonization of legislation: In all ICES member states there are many pieces of legislation governing activities in the marine environment. However, it is the case that some pieces of legislation operate in isolation and fail to identify efficiencies that might be found by consideration of additional legislation, be it transnational or national. For example, the fish health directive (2006/88/EC) governs the movement of all aquaculture products within and between EU member states. This legislation requires that shipments are inspected at point of departure to ensure that the requirements of the directive are met, i.e. no risk material is present in the shipment. This validation is provided on the basis of inspection at the point of origin and requires the identification of potential carrier organisms of listed diseases in the shipment, e.g. *Ostrea edulis*. While the shipment form (specified by the directive) offers a place for the identification of biofouling organisms or vectors, it only specifies that problem species should be listed. The authorization does not request that all non-target species should be listed. An opportunity is presented here to fulfil some other national legislative requirements by listing all non-target species found in shellfish consignment. Such a requirement would be to identify non-native species that might be imported into a area with a consignment of shellfish. However, the fish health directive does not provide for such restrictions and would require modification and harmonization with existing legislation (Habitats Directive 97/62/EC).

It has been highlighted that the methodology to improve plans for the removal and control of invasive species from transferred stocks should be continually updated and communicated. In order to facilitate this it should be incumbent upon policy makers to monitor and farmers to report exotic organisms (see next recommendations). To progress this goal it will be necessary to have a good knowledge of the marine biodiversity in shellfish areas and to be able to distinguish exotic species from indigenous fauna and flora. So in this context it is important to have monitoring networks. Monitoring programs developed for other purposes (i.e. for microbiological contamination, toxins and for EU Directives as water framework directive and marine strategy directive) can provide useful information and with some limited adjustments could be improved to include exotic species recording. For example, in France, there are a number of monitoring programs, e.g. REPHY for marine species of phytoplankton (http://envlit.ifremer.fr/surveillance/phytoplancton_phycotoxines/presentation), and REBENT for benthic invertebrates (soft substrates), macroalgae and angiosperms (http://www.rebent.org/) which facilitate the implementation of the Water Framework Directive. Additionally, fish stock assessments could provide additional observations for fish. These data are collected in separate databases but likely need to be connected.

Invasive Species Ireland – educational programs to identify species of concern. Information on species (invasive) communicated to user relevant groups and stakeholders including shellfish farmers.

5.7.3 Maintain an open dialogue

To best educate about and implement biosecurity issues with industry, agency and policy makers need to maintain a trusting open dialogue. Explaining the scientific implications of ignoring illegal introductions, transfers of shellfish from non-approved waters, or by-passing any regulatory protocol could have significant negative effects for growers not only in the local area, but throughout regions or countries. Understanding the economic implications, from both sides of the illegal activity, can be most beneficial over time for both industry and policy makers. Communication among parties that prevention costs less is an important part of this. There needs to be an in-depth understanding by policy makers and policy enforcers as to why industry might be tempted to act illegally in any part of the shellfish culture or processing sectors. Production schedules, market demand, opportunistic illegal sources of product can seem like a cost cutting process by industry in the short term, and this perspective needs to be comprehended by policy makers. Yet policy makers and law enforcement need to communicate that these actions can actually have a larger negative economic impact over time, than abiding by scientifically developed regulations that would take a much larger perspective into account. However, education and assistance must not be pedantic but supportive of the long-term survival and prosperity of the growers.

Industry needs to understand what the negative biological implications, ecosystem health impacts, and human health risks there may be with working outside of regulatory framework. Once this is understood, and a view toward the long term continuation of the shellfish culture business for the individual grower or groups of growers, adoption of a code of practice by industry to follow a regulatory framework can secure longevity for the growers.

Since the message about long term survivability of individual shellfish culture businesses may be understood and adopted by many, there is always the possibility of growers who might still think that the short term benefit could outweigh the long term success of the industry and work outside of the law. Two solutions exist to deal with this scenario.

One would be to have peer pressure by other industry members, who have adopted the code of practice and understand the long term effects of illegal activity, to address the culprit directly about the illegal action. The other would be to have appropriate enforcement of the regulations by appropriate police or natural resource personnel with cooperation from the courts to enforce significant fines for the illegal activity.

Consideration should be given to having a liaison employed by an agency or university to work with the industry in a liaison fashion to keep lines of communication open between industry and agencies. This person once accepted by industry could help to share knowledge from area to area, and allow industry thoughts to be exchanged with the resource managers and to update industry about the latest efforts in technology, disease reductions, product handling, marketing, and current research on shellfish culture.

5.8 Recommendations

There should be a presumption against routine introductions and transfer of molluscan shellfish, unless good scientific evidence proves otherwise. Prior to introductions, 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. Transfers should only occur through necessity and only be made following a full risk assessment.

Current legislation appears incomplete and not 'joined up' in dealing with the introduction and potential spread of alien species, associated hitch hikers and pathogens, unless listed within fish health or environmental regulation. Risk assessments should include possible effects of diseases (parasites, viruses and bacteria), genetic contamination and hitch hiking species. Consideration should 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.

Consultation on an introduction should be full, objective, be universally applied, follow full risk assessment and if approved, be so under quarantine. Imports of shellfish susceptible to notifiable diseases must be held in quarantine when the disease status of country of origin is uncertain; and the holding of shellfish for scientific purposes may be permitted provided that the animals are held in containment as quarantine conditions. A guideline to quarantine conditions is given in Appendix B.

A more dynamic and transparent system is needed, with standard guidelines including risk assessment, management advice and the identification of research goals. Because of the unknown risks of certain introductions the emphasis should be on precaution, if a species is allowed in it should be in quarantine – even through the F1 generation to assess reproductive behaviour and danger of disease transmission, prior to release.

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. Here, the guideline on best environmental practice (BEP) for the regulation and monitoring of marine aquaculture defined in MARAQUA (Read *et al.* 2001) for the European Union as well as for all countries defined by the FAO (FAO 1999) should be taken into account. These guidelines also include best available technique (BAT) and best management practice (BMP).

5.9 Conclusions

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, to controls with standardised guidelines, including aspects such as risk assessment, management advice, and the identification and application of research goals.

In general, all possible alternatives on the local level, e.g. employing hatchery or spat collection methods should be investigated before consideration of transfers as a last resort. If there are good commercial reasons for the transfer of a species, a robust standard of risk assessment should be applied, prior to release, to ensure that ecosystems are protected. Risk based surveillance is now an animal health requirement under Council Directive (EC) 2006/88 for the prevention and control of certain diseases, and models produced by each country should be designed to identify and quantify risks of disease introduction and spread. Transfers of shellfish are made routinely at all levels, by countries of differing environmental and disease status, highlighting the real risks of introducing listed and non-listed pests, parasites and diseases. There is a need for continued coordination in the development and application of legislation and codes of practice within and between countries; to minimise introduction and spread of invasive species and pathogenic organisms. Several tools, e.g. ICES Codes of Practice (ICES 2005), EC regulations, The Animal Health Code from Office International des Epizooties, and common veterinary practice are designed in order to assess risk, and avoid introductions of pathogenic agents and exotic species with the consignments. However, even if all guidelines and recommendations are followed, it is impossible to predict all possible effects of transfers and introductions, and to predict which disease problems may follow. The spread of pathogens frequently occurs ahead of the diagnostics. Learning from introductions and transfers of other bivalve species is therefore essential, to enable a proper risk assessment.

The strategy and principles to be followed by EC Directives involve; such that the burden to the public and private sectors is proportionate, finding the balance between control of non-wanted organisms and over-regulation and ensuring that regulation and surveillance is based on a transparent assessment of risk. An essential part in the development of any risk based assessment model is to ensure that it accurately identifies and quantifies those risks associated with all farms within a zone and provides early detection of possible impacts. Risk assessment requires regular review as industry practices evolve, increasing or decreasing risk on farm sites. Each farm is to receive a ranking (high, medium or low) based on criteria developed at a surveillance work stream workshop, frequency of inspection to be determined by the ranking of each site (Annex III of (EC) 2006/88).

A full risk assessment should include possible effects of diseases (parasites, viruses and bacteria), genetic contamination and hitch hiking species. The risk assessment should be undertaken to ensure safety to ecosystems, as the long term environmental and financial costs from introductions is unquantifiable in the long term. 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. Further, consideration should be given to the risk to native stocks from interbreeding and to the resultant progeny invading ecosystems being possibly infertile, creating an imbalance within an ecosystem. At the final destination a proper quarantine facility should be established to monitor transferred bivalves. The facility must be authorised as an Aquaculture Facility and all movements of live animals into the facility are to be recorded. If high risk were assessed, consideration should be given to growing the animals through the F1 generation to assess reproductive behaviour and the danger of disease transmission, prior to release.

However, there is little health protection against non listed species where there is little scientific knowledge of their impact or susceptibility to diseases. A full risk assessment would require a complete list of all non-target species to identify non-native species that might be imported into an area with a consignment of shellfish. For this goal it will be necessary to have a good knowledge of the marine biodiversity in shellfish areas and to be able to distinguish exotic species from indigenous fauna and flora. So in this context it is important to have monitoring networks. Monitoring programs developed for other purposes (i.e. for microbiological contamination, toxins and for EU Directives as water framework directive and marine strategy directive) can provide useful information and with some limited adjustments could be improved to include exotic species recording.

Overall, impact rather than financial considerations should be the prime concern. If a company wishes to profit from a transfer or introduction it should be prepared to undertake the proper scientific assessment of risk prior to release, as long term impacts can be serious and wide-ranging. Here, the guidelines on best environmental practice (BEP) for the regulation and monitoring of marine aquaculture as defined in the Monitoring and Regulation of Marine Aquaculture Programme (MARAQUA) (Read *et al.* 2001) for the European Union as well as for all countries defined by the FAO (FAO 1999), should be taken into account. These guidelines also include best available techniques (BAT) and best management practices (BMP).

However, the presence of "usually harmless – potentially harmful" organisms leads us to the problem on the existence of "stowaways", and the action of mechanical vectors. One organism will always carry another, and it seems impossible to obtain "clean" animals, in spite of long quarantines. An example of stowaways is hidden organisms in a consignment of bivalve spat. Frequently, batches contain more species than those they are supposed to contain, even if the batches have been (roughly) inspected, cleaned and graded. Mechanical vectors are passive carriers, which are not needed for the propagation of the species being carried. So even if all potential precautions were conducted properly the effects of transfers and introductions of bivalve molluscs are to some extent unpredictable. Moving molluscs, there is a risk of introducing pathogenic agents or of disturbing the balance between potentially pathogenic agents and host species in the recipient ecosystem.

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Appendix B: A guide to temporary quarantine conditions

The facility must be authorised as an Aquaculture Facility and all movements of live animals into the facility are to be recorded in the official Movement Record Book supplied.

1) The facility will be open to inspection by inspectors as deemed necessary.

2) The animals should be held in isolation in a system approved by the competent authority.

3) No animals or eggs are to be released alive from the facility without prior written approval.

4) All unwanted biological material must be removed in leak-proof containers and destroyed by incineration or autoclaving.

5) Access to the facility must be limited and come under the supervision of a nominated person.

6) A sign should be placed at all entrances stating 'Quarantine Area - Restricted Admittance'.

7) All effluent must be discharged to a tertiary treatment system or disinfected prior to discharge. There should be no direct drainage to prevent any accidental release of contaminated fluids.

8) All protective clothing, footwear, nets, buckets and other equipment must be solely dedicated to the facility and should not be removed without thorough disinfection.

6 Review the state of knowledge on the evidence for and effect of climate change on shellfish aquaculture distribution and production in ICES and countries worldwide (ToR d)

6.1 Background

Climate change has been defined by the United Nations Convention on Climate Change as the "change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods". The Intergovernmental Panel on Climate Change (IPCC) defines climate change as "a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and-or the variability of its properties, and that persists for an extended period, typically decades or longer" which includes changes resulting from both natural variability and human activity. The IPCC analyzed global climate observations and concluded that "warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level". Recent mean temperatures in the Northern Hemisphere are likely the highest in at least the past 1300 years. Precipitation and the frequency of large precipitation events have increased significantly in many ICES countries. These changes are linked with high confidence to increased runoff and the occurrence of earlier spring discharges and shifts in the geographic distribution and abundance of algae, plankton and fish. The increased carbon dioxide may also cause an acidification of the oceans, which may reduce the shell growth of bivalve molluscs (Gazeau *et al.* 2007). Climate change science is still in its early stages and the number and intensity of the impacts currently observed will likely increase markedly in coming years (Reid and Valdés, 2011). Consequently, the wide array of changes in ocean thermal characteristics, physical structure of the water column, ocean and sediment biogeochemistry and changes in theecology and physiology of marine organisms will undoubtedly impact bivalve aquaculture (University of Victoria 2000; Canadian Institute for Climate Studies 2000). The challenges to aquaculture scientists are to disentangle the impacts forced by an increase in both temperature and CO_2 as well as those caused by other natural and human stressors.

The WGMASC focus is to consider the current scientific evidence for, and effect of, climate change on shellfish aquaculture. To address this task, any available evidence on climate change impacts on cultured species needs to be accumulated and assessed.

The work of the WGMASC on this ToR includes reviewing reports on present climate change patterns and on projected changes in marine parameters that may affect shellfish culture. A starting point was to examine predictions of potential changes in the marine environment as revealed by different model scenarios. Given the close interaction between shellfish production and numerous natural ecological variations, it is important to assess any available evidence of potential climate change effects from a critical perspective. For example, can observations of summer mortalities in the oyster *Crassostrea gigas* be attributed to climate change in certain European countries or simply be a result of poor broodstock selection and/or management? Evidence of climate change impacts on shellfish culture should ideally be based on cause-effect linkage rather than correlations, which can reflect autocorrelations, anti-aliasing, and/or random processes. Consequently, our work on this topic attempted to extract scientific evidence that is consistent with a climate-change effect, but with an awareness of impacts caused by other natural or anthropogenic stressors and possible synergistic or antagonistic effects of multiple stressors (i.e. Reid and Valdés, 2011).

6.2 Related ICES activities on Climate Change

Over the past century, ICES has played a leading role in developing an understanding of the effects of climate and environmental variability in the North Atlantic and Arctic oceans. This WGMASC term of reference is closely linked to other ICES expert group activities and with the OSPAR request for ICES "to prepare an assessment of what is known of the changes in the distribution and abundance of marine species in the OSPAR maritime area in relation to changes in hydrodynamics and sea temperature." The Council currently publishes the annual ICES Report on Ocean Climate to inform of the work done by ICES on climate change and to help provide future direction on policy development on this issue within the Council. The Steering Group on Climate Change [SGCC], later renamed the Science Strategic Initiative on Climate Change [SSICC], was created to look at the research, services and operational issues related to Climate Change supported by ICES in their expert groups, to assess the quality and adequacy of the assessment process, and to manage the establishment of a programme in Climate Change. The SSICC integrates the work of expert groups in climate change towards common and concrete objectives and is tasked to produce the best scientific base in climate change in order to:

- understand the functioning of marine ecosystems under a changing climate;
- understand the impacts of climate change on marine ecosystems;
- identify the contribution of feedbacks from the oceans to climate change;
- analyse uncertainties on projections/scenarios of evolution of climate change;
- develop and evaluate options for mitigation and adaptation for a sustainable use of ecosystems;
- promote observations and existing time series studies and the establishment of new time series with the aim of inclusion of these data sets in the ICES data holdings and make the data available in a short period of time;
- facilitate risk analyses in climate change projections;
- provide information to the public and assist policy makers and stakeholders in their decisions.

The scientific tasks of the SSICC are:

- Identify key connections on the biology, physical and chemical system interacting in climate change.
- Identify sentinel and sensitive organisms and communities as indicators of climate change.
- Integrate the oceanic observing system in risk analysis on climate change.
- Identify and disentangle the impacts of natural climatic variability and anthropogenic drivers in marine ecosystems to enable better management.
- Develop predictive capabilities for the impact of climate change on marine ecosystems.

The ICES Benthos Ecology Working Group (BEWG) initiated a Workshop on Climate related Benthos Processes in the North Sea (WKCBNS; 8 to 11 December 2008 in Wilhelmshaven, Germany) to discuss research activities concerning the North Sea benthic ecosystem. This workshop report (ICES 2009a) included a review of the results of the North Sea Benthos Project 2000 (NSBP), an evaluation and prioritization of climate-related benthic processes, the development of research approaches and recommendations for the study of key benthic processes affected by climate change, and the important role that modelling approaches will play in addressing this research area. A starting point for addressing their workshop objectives was the prioritization of current climate change hypotheses as they relate to the benthos (see Annex 1). This was a valuable contribution as a starting point for the WGMASC to address related climate change issues from the perspective of potential impacts on shellfish aquaculture. Information contained in this workshop report (ICES 2009a) has been instrumental in our ongoing efforts to review the available knowledge on climate change effects on shellfish culture.

A joint PICES and the ICES working group (Working Group on Forecasting Climate Change Impacts on Fish and Shellfish: WGFCCIFS) was formed to develop:

- frameworks and methodologies for forecasting the impacts of climate change on marine ecosystems, with particular emphasis on the distribution, abundance and production of commercial fish and shellfish;
- methodologies applied in designated case studies;
- techniques for estimating and communicating uncertainty in forecasts;
- strategies for research and management under climate change scenarios, given the limitations of our forecasts.

These WGFCCIFS terms of reference include the promotion of research on climate change impacts on marine ecosystems, in collaboration with relevant expert groups in PICES and ICES, through coordinated communication, exchange of methodology, and organization of meetings to discuss and publish results (PICES/ICES 2009). The WGFCCIFS is focused on the development of standardized quantitative frameworks for forecasting climate change impacts on commercially important fish and shellfish. The WGFCCIFS published a volume in 2011 on "Climate Change Effects on Fish and Fisheries: Forecasting Impacts, Assessing Ecosystem Responses, and Evaluating Management Strategies" in the July issue of ICES *Journal of Marine Science*. The papers emphasize the complexity and multifaceted issues facing scientists trying to understand and predict future implications of climate change effects on fish and shellfish (PICES/ICES 2011). This volume also emphasized that analytical teams attempting to project the future of fisheries should include social scientists, stakeholders, and economists to project societal and market changes. The WGMASC has attempted to limit overlap in our Terms of Reference with other ICES expert groups by focusing on documenting available evidence of commercial cultured shellfish responses to climate shifts, however, our activities are clearly linked to all ICES groups working on the climate change issues. It is therefore important to integrate activities through enhanced communication/linkage between expert groups.

6.3 Background on Climate Change and Effects on Marine Ecology

A first step towards understanding climate change effects on cultured shellfish in ICES countries is the identification of (1) the magnitude of observed and forecasted climate change (meteorology, physical and chemical oceanography) in the North Atlantic and (2) hypotheses on direct and tropho-dynamic effects on cultured species. Both activities emphasize identification of impacts known to influence the production of high quality commercial shellfish products. Towards achieving the first objective, compilations of climate change observations and scenarios were reviewed and summarized (e.g. International Panel on Climate Change Synthesis Report [IPCC 2007]; the ICES review of the effect of climate change on the distribution and abundance of marine species in the OSPAR Maritime Area [Tasker *et al.* 2008]; Philippart *et al.* 2011; Reid and Valdés, 2011; Hughes *et al.* 2011; Denman *et al.* 2011). Marine responses to climate change include a wide range of alterations to important biological and physicochemical patterns and processes ranging from ocean circulation and primary productivity to biodiversity, biogeography, and evolution.

"Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level" (IPCC 2007). There is very high confidence in the conclusion that average Northern Hemisphere temperatures during the last 50 years were higher than during any other similar period in the last 500 years and are likely the highest in at least the past 1300 years. The global mean temperature of the air and the sea surface has risen at a rate of ~ 0.074 °C per decade since 1750. Philippart *et al.* (2011) summarized the pattern of sea temperature over the last century in the European Seas as having fluctuated from generally cold conditions in the early 1900s to a warm period from the 1920s to the 1950s. This area was cool again through the 1960s and 1970s, followed by recent warming that commenced in the mid 1980s. The global ocean has taking up over 80% of the heat being added to the climate system and average water temperature has increased to depths of at least 3000m. The North Atlantic has experienced an increase in upper ocean heat content since the 1960s, and the rate of increase has been greater there than anywhere else on the globe (Figure 6.1 as reported in Reid and Valdés, 2011).

Projections of future climate change in the near term, based on modelling of different scenarios, indicate that an atmospheric warming of about 0.2°C per decade over the next two decades. Assuming continued green house gas (GHG) emissions at or above current rates, further warming will occur during the 21st century and will induce many changes in the global climate system that would very likely be larger than those observed during the 20th century. A summary of the current state of knowledge on observed and projected changes in sea surface temperature of European Seas is provided in Table 6.1. The observed and predicted increases in temperature under climate change are generally higher in northern than in southern European seas and in enclosed than in open systems (Philippart *et al.* 2011).

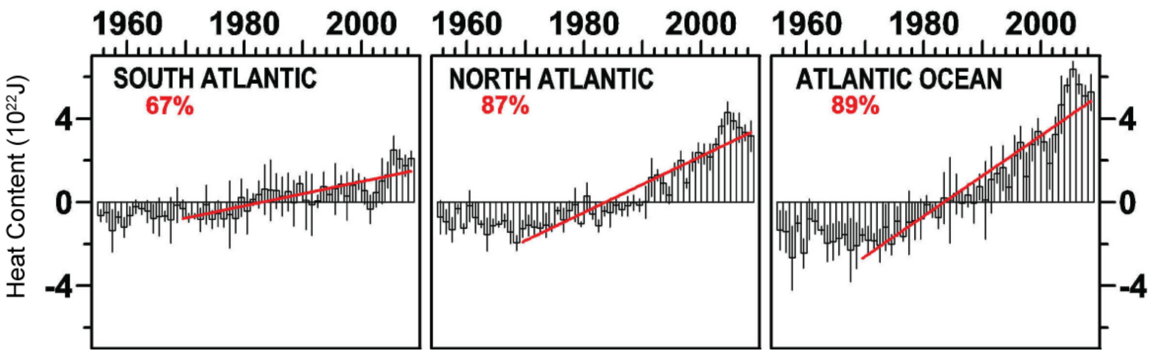

Figure 6.1. Time-series of yearly ocean heat content for the 0–700 m layer of the Atlantic Ocean (with percentage variance accounted for by the linear trend shown in red); (Source: Levitus *et al.*, 2009 as reported in Reid and Valdés, 2011).

Table 6.1. Observed and projected changes in sea surface temperature of European Seas (source: Philippart *et al.* 2011).

European Sea	Observed Change	Predicted Change
Arctic Ocean	ca. +0.2 °C per decade (1965–'95)	+4 to 7 °C (1990s–2090s)
Barents Sea	+0.12 °C (1982–2006)	+1 to 2 °C (1990s–2080s)
Nordic Seas	+0.85 °C (1982–2006)	+1 to 2 °C (1990s–2080s)
NE Atlantic	+1 °C (1975–2005)	+2 °C (1990s–2090s)
North Sea	+1.31 °C (1982–2006)	+0.8 °C (1990s–2040s)
Baltic Sea	+1.35 °C (1982–2006)	+2 to 4 °C (1990s–2090s)
CB Shelf	+0.72 °C (1982–2006)	+1.5 to 5 °C (1990s–2090s)
Iberian upwelling	+0.68 °C (1982–2006)	+1.4 to 2.4 °C (1960/1990–2070/2100)
Mediterranean	+0.71 °C (1982–2006)	+2.6 °C (1961/1990–2070/2099)
Black Sea	+0.96 °C (1982–2006)	

Some consequences of global warming include a rise in sea level, resulting from thermal expansion and ice-melt, and changes in the intensity and frequency of storms, precipitation, river run-off, oxygen concentration, and wind-driven circulation. Arctic sea-ice extent has demonstrated a more or less steady decrease since the late 1970s, leading to predictions that perennial ice may give way to seasonal ice cover within 10–50 years. Precipitation has increased significantly between 1900 and 2005 in eastern parts of North America, northern Europe and northern and central Asia. Increased precipitation/run-off may lead to greater coastal eutrophication and/or an increase in contaminant loads. Local wind patterns can also affect water-column stability and nutrient availability below the pycnocline. This is particularly evident in regions where upwelling occurs. Upwelling regions (e.g. off the Iberian Peninsula) support a significant fraction of global shellfish aquaculture owing to the enhanced supply of phytoplankton.

It appears likely that the frequency of heavy precipitation events (or proportion of total rainfall from heavy falls) has increased over most areas and the incidence of extreme high sea level has increased. Global average sea level has risen at an average rate of 1.8 mm per year over 1961 to 2003 and at an average rate of about 3.1 mm per year from 1993 to 2003. The vulnerability of coastal areas to flooding varies and the most susceptible regions within Europe are England, the Netherlands, Denmark, Germany, Italy, and Poland. Areas with a lower tidal range, such as the Baltic and the Mediterranean, may also be more vulnerable to sea level rise than the Atlantic and

North Sea coasts. Shorelines south of 40 °N on the Atlantic coast of the US have been also been shown to be among the most vulnerable. Although there is considerable uncertainty in model predictions, global sea level is projected to rise between 0.18 m and 0.59 m by the end of the 21st century. The future impact of sea level rise is likely to be mainly socio-economic, owing to the flooding of coastal areas.

Shellfish aquaculture is entirely dependent on the availability of natural trophic resources, including phytoplankton. It is expected that the largest changes in marine ecosystems will occur at the lower trophic levels, and evidence exists to suggest that phytoplankton seasonal cycles have shifted (Edwards and Richardson 2004) including occurrence of harmful algae (Hallegraeff 2010). Climate change is closely coupled to variations in the productivity of the ocean. For increases in global average temperature exceeding 1.5 to 2.5°C there are projected to be major changes in ecosystem structure and function, species' ecological interactions and shifts in species' geographical ranges, with predominantly negative consequences for biodiversity and ecosystem goods and services. Higher temperature should favour an increase in primary production. However, rising surface water temperature will also lead to increased stratification and greater nutrient limitation. The net result is expected to be a reduction in global primary production, but the present ability to predict future changes is limited.

The first analyses of remote sensing estimates of global phytoplankton biomass estimated an overall increase of ~22 % in the global average of oceanic chlorophyll concentration between 1979 and 2002. Later studies indicated a global increase of ~ 4.1 % between 1998 and 2003, with the largest change (+ 10.4 %) occurring in coastal regions. This increase in chlorophyll is likely caused by enhanced stratification from surface warming and the resulting reduction in light limitation for phytoplankton growth. The risk of harmful algal blooms (HABs) may increase as a result of environmental conditions expected with climate change. Moore *et al.* (2011) showed that warm air and water temperatures, low stream-flow, low winds, and small tidal variability preceded HAB events during the past 30 years, a condition that would have significant consequences to shellfish cultivation. This information was used to project climate impacts on toxic HABs in the Pacific Northwest in a future warmer climate. Smaller phytoplankton cell sizes, which are largely unavailable for consumption by farmed bivalves, are also expected at higher temperatures, and a shift to smaller cells is favoured under strong stratification because small cells are more effective in acquiring nutrients and less susceptible to gravitational settling than large cells. Major changes in physiology (e.g. increased respiration), foodwebs (e.g. increased predation), and biogeochemical processes (e.g. acidification and sedimentation rates) would occur at the scale of the global ocean in parallel with changes in phytoplankton size and production.

Large scale climate changes have been shown to substantially alter estuarine zooplankton population dynamics owing to interspecies differences in life histories (Costello *et al.* 2006). In the North Atlantic, substantial ecosystem changes observed across multiple trophic levels were demonstrated to be associated with temperature increases above a critical thermal threshold of 9–10 °C. Ecological regime shifts also occurred in the central Baltic and North Sea in the late 1980s and zooplankton and fish were especially affected. It is likely that these recently observed ecological responses to climate change in the North Atlantic will continue into the near future if current trends in sea ice, freshwater export, and surface ocean salinity continue. A meta–analysis of long-term datasets demonstrated that the changes in distribution, abundance, and other characteristics (particularly seasonality) of marine biota are consistent with expected climate effects (Tasker *et al.* 2008). This included 85 cases of changes in benthos and it was noted that if climate change results in temperature conditions outside the recent historical range of natural variation, major effects on at least some species and communities would be likely.

Tasker *et al.* (2008) concluded "climate-related changes in a range of physical and chemical conditions in the sea will, in turn, affect species composition directly or indirectly and, therefore, the trophic structure of benthic communities. Changes in the latitudinal distribution of some species may be expected with predicted changes in water temperature, with species expanding outside their historical ranges into more northerly or less coastal areas (Table 6.2). Many marine species are moving northwards, however, the rate and direction of this migration differs for the diverse seas and species (Philippart *et al.* 2011). For most open seas, there is evidence of species moving northwards and/or northern species being replaced by more southern ones. For enclosed seas that are highly influenced by river runoff, species movements and community shifts are expected to be higher than in open seas and oceans.

Table 6.2. Summary of scenarios of effects of climate change on species composition of marine communities in European seas (Philippart *et al.* 2011).

General trends	System-specific expectations
Increase in temperature	Higher in northern than in southern systems Higher in enclosed than in open systems
Impacts on ecosystems	Stronger for enclosed than for open systems
Northward movements	Higher in northern than in southern systems Stronger for open than for enclosed systems
Shifts in species composition	From northern to southern species (open systems) From ice-bound to aquatic species (northern systems) From marine to freshwater species (Baltic Sea) From endemic to congeneric species (enclosed systems)

Globally, the potential for food production is projected to increase with increases in local average temperature over a range of 1 to 3°C, but above this it is projected to decrease. This will increase the global need for aquaculture products at a time when coastal regions that currently support most of this activity are increasingly stressed due to the "coastal squeeze" between intertidal habitat and sea level rise defences, increase in extreme weather events, the steepening of the intertidal slope, sediment coarsening, contaminant run-off, upstream saline water intrusion in estuarine environments, etc.

6.4 Available Evidence on Climate Change Effects on Shellfish Aquaculture

The ICES workshop report on climate related benthos processes in the North Sea (WKCBNS; ICES 2009a) identified and prioritized hypotheses on the effects of climate change on the benthos. Table 6.3 summarizes these results and includes an additional column on the urgency of climate change issues from the perspective of its perceived influence on shellfish aquaculture. The following sub-sections report on the available evidence supporting some of these hypotheses.

Table 6.3. High priority hypotheses on climate change issues related to benthic structure and processes. All hypotheses identified were classified by importance (hot topic) and urgency of the issue from the perspectives of impacts on benthic communities (WKCBNS prioritization) and bivalve aquaculture (WGMASC prioritization). Adapted from ICES (2009a).

Hypothesis	HOT TOPIC	URGENCY (WKCBNS)	URGENCY (WGMASC)
Frequency/intensity storms natural disturbance effect	yes	high	high
Production/biomass process changes driven by climate	yes	high	high
Community changes – habitat alteration through climate change	yes	high	high
Altered currents – frontal positions – primary production - food	yes	high	high
Cumulative effect of anthropogenic disturbance and climate change	yes	high	high
Effect of interaction in anthropogenic drivers and climate change drivers	yes	high	high
Change in timing of spawning and spatial distribution of settlement	yes	high	high
Stratification – temporal mismatch	yes	high	high
Changing wind directions – effect on larval transport and species distributions	yes	high	high
Changes in nutrient fluxes/advection	yes	negligible	negligible
Poleward shifts in latitudinal distributions of species	yes	negligible	high
Rising temp = greater invasive species	yes	negligible	high
Acidification effects	yes	negligible	high
Reduced mixing - deoxygenation	negligible	negligible	medium
Parisites infection rates – consequences for survival and reproduction	negligible	negligible	high
Reduced mixing – HABs effect on benthos food webs (aquaculture)	negligible	negligible	medium
Climatic induced changes in macro-phytobenthic plants – influence on species composition	negligible	negligible	slight (seed collection)
Change in pollutant runoff due to climate change effecting reproduction and local extinctions	no	no	*possible
Alternative production export to deeper waters	no	no	no

*** The WGMASC considered additional effects on shellfish product quality through contaminant bioaccumulation.**

6.4.1 Effects of Temperature Change on Shellfish Species Distribution

Water temperature is a key external factor mediating bivalve growth owing to the direct influence on a number of the physiological components of growth and may lead to mass mortalities if temperature tolerances are exceeded. It may be expected that species with higher temperature tolerances will be better able to cope with global warming. In addition, the more warm-adapted species may be at a disadvantage because they tend to live closer to their absolute tolerance limits and have lower acclimation potentials. Consequently, the temperature tolerances of individuals may be a useful indicator of a population's potential to persist or become extinct in response to climate change (Cascade *et al.* 2011). Exceptionally high and constant water temperatures in the Northwestern Mediterranean (23–24 C) have been identified as possibly contributing to mass mortality events of invertebrates, including bivalves (Perez *et al.*

2000). However, it is often difficult to assign causality for growth and mortality changes to temperature variations owing to the complex interplay that exists between a wide array of exogenous and endogenous forcing factors that control growth and survival and population specific acclimation responses (e.g. Cascade *et al.*, 2011). For example, a bivalve species residing in a more tropical climate is known to be less able to adapt to temperature variation than the same species residing in temperate waters, owing to the wider thermal tolerance of the later (Compton *et al.*, 2007).

The strongest evidence of responses of benthic species (including bivalve molluscs held in bottom and suspended culture) that would be expected as a result of climate change is supplied in reports of benthic species expanding outside their historical ranges into more northerly or less coastal areas (e.g. Tasker *et al.* 2008). This can result from the die-off of species commonly associated with relatively warmer waters due to anomalously cold winter conditions and outbreaks of species commonly associated with relatively colder water. Intertidal shellfish are particularly susceptible to occasional mortality events during prolonged periods of hot weather and these would be likely to increase in frequency under warmer conditions. For example, the recent disappearance of *Macoma balthica* from the Spanish part of the Bay of Biscay has been attributed to increased maintenance metabolic rates caused by short-term, but frequent exposure to elevated temperatures resulting in increasing summer maximal temperatures (Jansen *et al.*, 2006). Although this is not a cultured species, possible latitudinal shifts in the geographic range of traditional and potential aquaculture species bivalves will affect aquaculture trends.

The Pacific oyster *Crassostrea gigas*, which was first introduced to Europe by Dutch farmers in 1964, has developed explosively and is expanding its geographical range northwards (Wrange *et al.*, 2009); (Figure 6.2). Diederich *et al.* (2004 and 2005) studied how *C. gigas* became established on natural mussel beds in the vicinity of an oyster farm near the island of Sylt (northern Wadden Sea, eastern North Sea) where it was introduced. It took 17 years before a large population was established. Troost (2010) examined the expected effects of climate change on the distribution of *C. gigas* and inferred that warm summers are the main determinant for recruitment success that promote extensive spatfall near its northern distribution limit. It was concluded that the further invasion of *C. gigas* in the northern Wadden Sea will depend on higher late-summer water temperatures. Global warming may therefore increase spatfall success of *C. gigas* in summer and survival of spat in the following winter, leading to further population increase. The increase in mean water temperatures and frequency of high summer temperatures in Scandinavian waters during the recent decades facilitated the spread and establishment of Pacific oysters in Denmark, Sweden and Norway during 2006 and onwards (Wrange *et al.*, 2009). As an example, the massive occurrence of Pacific oysters observed in Sweden in 2007 correlated with unusually warm summer water temperatures in 2006. Water currents along the Norwegian Skagerrak coast are westward, and continue northward along the Norwegian western coast (Sætre *et al.*, 1988). The current pattern and time-scale of weeks to months for water transport from these waters to the Swedish west coast and Norwegian southern coast is within the range of the planktonic larval period of the Pacific oyster (Brandt *et al.*, 2008; Wrange *et al.*, 2010). The native European flatoyster (*Ostrea edulis*) has its northern distribution on the Norwegian south-western coast where it is cultured mainly in land-locked waterbodies that have higher summer temperature than the coastal and oceanic environment (Strand and Vølstad, 1997). Increased temperature in the coastal environment may expand the geographical distribution to these areas, and overlap with the distribution of Pacific oysters has been suggested as a potential conflict (Wrange *et al.*, 2009).

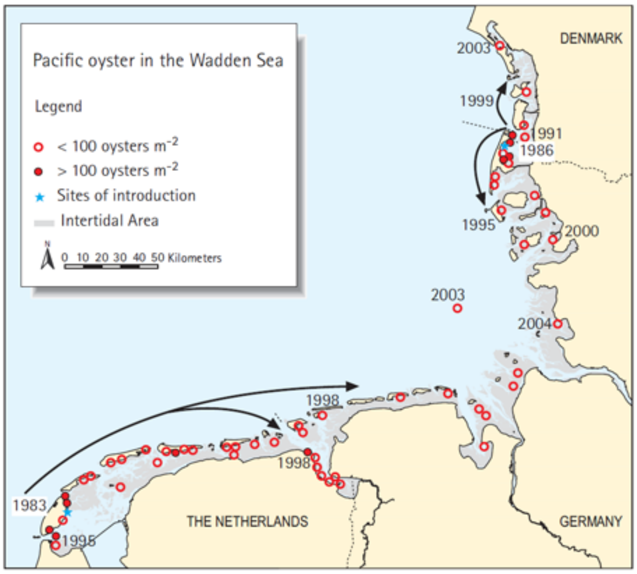

Figure 6.2. ***Crassostrea gigas*** **expansion in the Wadden Sea. Blue stars indicate introduction sites in Texel (the Netherlands) and Sylt (Germany). Years indicate first records of settlement. Circles refer to mean Pacific oyster abundance in 2003 (source Reise** ***et al.*****, 2005).**

In Ireland, Pacific oyster culture has been conducted since 1974. The conventional wisdom at the time of this species introduction was that ambient water temperatures were such that the species could not successfully reproduce. However, in recent years successful recruitment has been observed in a number of bays where aquaculture of oysters is ongoing. The successful recruitment appears to be mediated by proximity to aquaculture activities and provision of suitable settlement substrate (clean boulders and mixed sedimentary material including mussel reefs). Localised hydrodynamic conditions (residence time) may also mediate recruitment events (Kochmann *et al.*, in prep). Temperature profiles from Malin Head in the north of Ireland and adjacent to one location where successful recruitment has been observed (Lough Swilly) demonstrates a gradual increase in mean water temperatures over a 25 year period. It is anticipated that this temperature increase, along with an increased standing stock (spawning biomass) has facilitated successful recruitment at this site.

The Manila clam (*Ruditapes philippinarum*) was introduced in Europe for aquaculture during the 1970s and 1980s. At the time, successful self-recruitment was considered unlikely due to thermal thresholds for reproduction. However, there is growing evidence that the colonization ability of the species has been enhanced with warming trends. For example, this species has recently formed self-sustaining populations in the wild and are of sufficient size to sustain small commercial fisheries in southern England (Laruelle *et al.*, 1994 and Caldow *et al.*, 2007). With warming seawater temperatures, *R. philippinarum* successfully competes with other functionally similar native clams where it becomes established.

Intertidal populations of *Mytilus edulis* have experienced catastrophic mortality directly associated with summer high temperatures along the southern portion of its range on the Atlantic coast of the United States. A geographic contraction of the southern range has occurred, shifting the range edge approximately 350 km north of the previouslimit at Cape Hatteras (Jones *et al.*, 2010). The southern distribution has not changed for *M. edulis* along the eastern Atlantic (Wethey *et al.*, 2011), but the northern range appears to be expanding. Berge *et al.* (2005, 2006) examined interannual variations in ocean temperatures and the increased northward volume transport of Atlantic water and suggested that a recently discovered population of *M. edulis* L. in the high Arctic Archipelago of Svalbard represented a northward extension of the distribution range of blue mussels. This is the first observation of the presence of blue mussels since the Viking Age. These authors present data indicating that most of the mussels settled as spat in 2002, and that larvae were transported by the West Spitsbergen Current northwards from the Norwegian coast to Svalbard the same year. This extension of the blue mussels' distribution range was apparently made possible by the increased northward mass transport of warm Atlantic water resulting in elevated sea-surface temperatures in the North Atlantic. The cockle *Cerastoderma edule* and clam *Mya arenaria* have also expanded their northern distributions, possible as a result of mild winters in northwestern European estuaries (reviewed by Philippart *et al.*, 2003).

Latitudinal shifts in shellfish distribution and population dynamics may also result from climate change effects on predator/prey relationships. Mortality of juvenile bivalves appears to be related to food availability and reproductive strategies are closely linked to exploiting the spring phytoplankton bloom and avoiding peak predator abundance (Philippart el al. 2003). Temperature changes can cause a mismatch between spawning, phytoplankton production and predator abundance; resulting in high shellfish mortality, low recruitment and cascading effects through higher trophic levels (Philippart el al. 2003). Beukema and Dekker (2005) studied possible causes of recent bivalve recruitment failure in the Wadden Sea by comparing long-term data sets (1973 to 2002) of the annual abundance of spat of three of the most important species of bivalves (*C. edule*, *M. arenaria*, and *M. balthica*). They concluded that the recruitment trends are governed primarily by natural processes, in particular increases in predation pressure on early benthic stages, which in turn appear to be largely governed by the warming climate. Freitas *et al.* (2007) compared the temperature sensitivity of epibenthic predators with that of their bivalve prey and showed that crustaceans have higher temperature sensitivity and tolerance range compared with both their potential predators and with their bivalve prey. They suggested that a temperature increase can potentially lead to an overall higher predation pressure in these systems with negative impacts on bivalve recruitment. However, prevailing food conditions for bivalves and predators will determine to what extent the potential impacts of an increase in temperature will be realized.

Shepard *et al.* (2010) suggested that a significant increasing trend in juvenile scallop *Pecten maximus* density around the Isle of Man was association with rising mean spring temperatures in the Irish Sea. Gonadal somatic index of adult scallops and temperature were positively correlated and they suggested that this relationships supports the hypothesis that a greater gamete production associated with ocean warming may be primarily responsible for observed increases in recruitment success and catches in a commercially important shellfish stock. Although this is based on a wild stocks fishery, it has relevance for aquaculture activities including stock enhancement and sea ranching.

As cultivated shellfish experience extreme thermal conditions, which will occur more rapidly for inter-tidally cultivated species, they will become more susceptible to bacterial, viral and parasitic infections (Gubbins, 2006). Cook *et al.* (1998) showed from empirical analysis that increasing winter temperatures during the early 1990s were associated with epizootic outbreaks of Dermo disease (*Perkinsus marinus*) in the eastern oyster, *Crassostrea virginica*. This is consistent with reports that increasing winter water temperatures in the north-eastern USA have been important in the recent outbreak of *P. marinus* epizootics. A case study revealing potential interactions between increased temperature, parasites and commercial shellfish is the Iceland scallop (*Chlamys islandica*) fishery, which started in 1970 in Breiðifjördur. This fishery provided yearly catches of about 9000 tonnes between 1993 and 2000, but declined drastically between 2001 and 2008. Catch indices in 2008 amounted to only 13% of the average for 1993–2000 (Eiríksson 2009). The Iceland scallop is distributed within the Subarctic transitional zone at maximum sea temperatures of 12–15°C (Sundet, 1988; Hovgaard *et al.*, 2001). The period from 1993 to 2003 was characterized by a steady increase in summer sea surface temperature in Iceland, with the highest estimated temperature of the previous century occurring in 2003 (Jónasson *et al.* 2006). The bottom sea temperature usually ranges from 0 to 10 °C on the scallop grounds (Eiríksson 1986), however, the temperature data from these grounds show the highest recording of 12.2°C in Breiðifjördur at 15-m depths in August 2003 (Eydal 2003).

An experimental study by Jonasson *et al.* (2004) showed that scallops collected during late summer can tolerate temperatures up to 13°C, at least for up to 21 d, but there is considerable mortality at 14°C. The rising temperature in Breiðifjördur during recent years has therefore brought the summer maximum temperature close to the apparent temperature tolerance of the stock, e.g. 12.2°C in August 2003 (Jonasson *et al.*, 2004). However, it does not appear that the direct effects of temperature may be the sole factor responsible for the dramatic decline in the Iceland scallop stocks during the last years. Other factors, that are often temperature-dependent, such as diseases, may be equally or even more responsible (Jonasson *et al.* 2004). During the decline in the scallop fishery, nearly 100% of scallops greater than 60 mm shell height contained a apicomplexan parasite. The adductor muscles was most heavily infected and gonad development was impaired in infected individuals (Kristmundsson and Helgason 2009).The increase in temperature over the scallop grounds may have caused the scallops to be more susceptible to the infections and/or caused the increase in the number of the apicomplexan parasites in the area that caused mortality in the scallop stock. Furthermore, the warming trend could have created more favourable conditions for the parasite to proliferate inside the shells, resulting in increased natural mortality in the scallop stock.

Since 1998, abalone (*Haliotis tuberculata)* mass mortalities have been occurring regularly in wild populations in France during their reproductive period and in conjunction with seawater summer temperature maxima and the presence of the pathogen *Vibrio harveyi*. Travers *et al.* (2009) showed that a difference of only 1°C in temperature had a highly significant impact on abalone mortalities. The recent epidemic losses of European abalone appeared in conjunction with host reproductive stress, elevated temperatures and presence of *V. harveyi.* Temperature-dependent vibriosis represents a new case of an emerging disease associated with global warming.

Shellfish growth and disease rates vary greatly along the estuarine salinity transition between fresh and marine waters (e.g. Levinton *et al.* 2011). Global warming related changes in precipitation and river discharge may alter estuarine salinity and shift regions of low salinity and disease refuge away from regions with optimal shellfish bottom habitat. This change would negatively impact shellfish reproduction and survival. Temperature is an additional factor for oyster survival, and recent temperature increases have increased vulnerability to disease in higher salinity regions. In addition, climate change related factors including temperature, salinity, oxygen, and food availability can affect immune parameters of molluscs (Fisher, 1988).

Ecophysiological modelling provides a means of predicting the net consequence of temperature changes. Ferreira *et al.* (2008) developed a modelling framework that enables the integrated analyses of bivalve–environment interrelations affecting overall production at system-scales and used this approach to examine the potential effects of global climate change on mussel and oyster production. These authors considered an increase in water temperature of 1°C and 4°C for Strangford Lough (Northern Ireland) and predicted a reduction in aquaculture productivity and a decrease in both the mean weight and mean length of individuals. An increase of 1°C in the water temperature is predicted to lead to a reduction of about 50% in mussel production and less than 8% in Pacific oyster production, and an increase of 4°C could result in a reduction of 70% in mussel production and less than 8% in Pacific oyster production.

Malaku-Canu *et al.* (2010) also employed dynamic modelling to explore the impacts of climate change on local aquaculture activities in the temperate Venice Lagoon and the importance of implementing adaptive management policies to mitigate adverse effects. This study investigated how the seasonal dynamics of temperature and biogeochemical properties affect the rearing of the Manila clam *Ruditapes philippinarum*, an economically important species for local fisheries and aquaculture. A bioenergetics model describing the physiology, growth and population dynamics of clams in this study area was integrated with a hierarchy of models to analyse the impacts on *R. philippinarum* of state-of-the-art climate change projections for the region. They compared the results of model simulations for present day climate conditions (1961–1990) with a future scenario (2071 to 2100) and predicted a 13% decline in potential clam production in the area. The difference is mainly caused by direct clam responses to higher water temperatures and, to a lesser extent, by changes in seasonal patterns of freshwater and nutrient input from rivers that reduce plankton productivity and affect habitat suitability for clam growth and aquaculture. The authors highlight the need for management policies to mitigate the adverse effects of climate change. It is important to note that an important source of uncertainty in these predictions is the possibility that the clams may have the capacity for thermal adaptation over the timescale of climate change.

6.4.2 Ocean Acidification Effects on Shellfish

Approximately one third of anthropogenic CO_2 emissions have been absorbed by the oceans (Sabine *et al.* 2004). As the oceans absorb CO_2, the dissolved CO_2 reacts with water to produce bicarbonate ions (HCO_3^-) by consumption of carbonate ions (CO_3^{2-}):

$CO_2 + H_2O + CO_3^{2-} \rightarrow 2HCO_3^-$.

The result is less carbonate and more bicarbonate in seawater. In addition, the depletion of carbonate results in much of the CO_2 remaining as CO_2 and the production of bicarbonate by reaction directly with water:

$CO_2 + H_2O \rightarrow H^+ + HCO_3^-$.

The resulting increase in hydrogen ions reduces pH. The pH of ocean surface water has declined by ~0.1, a 26% increase in acidity, since humans began emitting large quantities of CO_2 (Orr *et al.* 2005; IPCC 2007a). It is estimated that the pH of the oceans will decline by an additional 0.3 to 0.4 pH units by 2100 (IPCC 2007b). Figure 6.3 shows projections of global patterns in decreasing surface pH to 2100 provided by the Canadian Earth System Model (Denman *et al.* 2011). Other model results reviewed by Denman *et al.* (2011) indicate that a projected decrease in global mean surface pH to ~ 7.7 by the end of 2100 would be caused primarily by the amount of anthropogenic CO_2 absorbed by the ocean and not by effects related to increasing surface temperature and subsurface stratification. This pH change will fundamentally alter the seawater chemistry to which marine life has adapted over millions of years.

Bivalve molluscs produce calcareous shells following the simplified reaction:

$CO_3^{2-} + Ca^{2+} \rightarrow CaCO_3$.

The calcification process mainly depends on the availability of CO_3^{2-}, which declines at elevated pCO_2. Bivalve mollusks require the availability of sufficient amounts of CO_3^{2-} for shell formation and excessive ocean acidification can be expected to decrease the ability of bivalves to build their shells. Research into the effects of increased ocean acidification on all marine calcifiers, as summarized by Kleypas *et al.* (2006), has concentrated on addressing:

- how calcification rates vary with calcium carbonate saturation state; and
- the effects of changing calcification and dissolution rates on the ocean carbon cycle and the capacity of the ocean to take up CO_2 from the atmosphere.

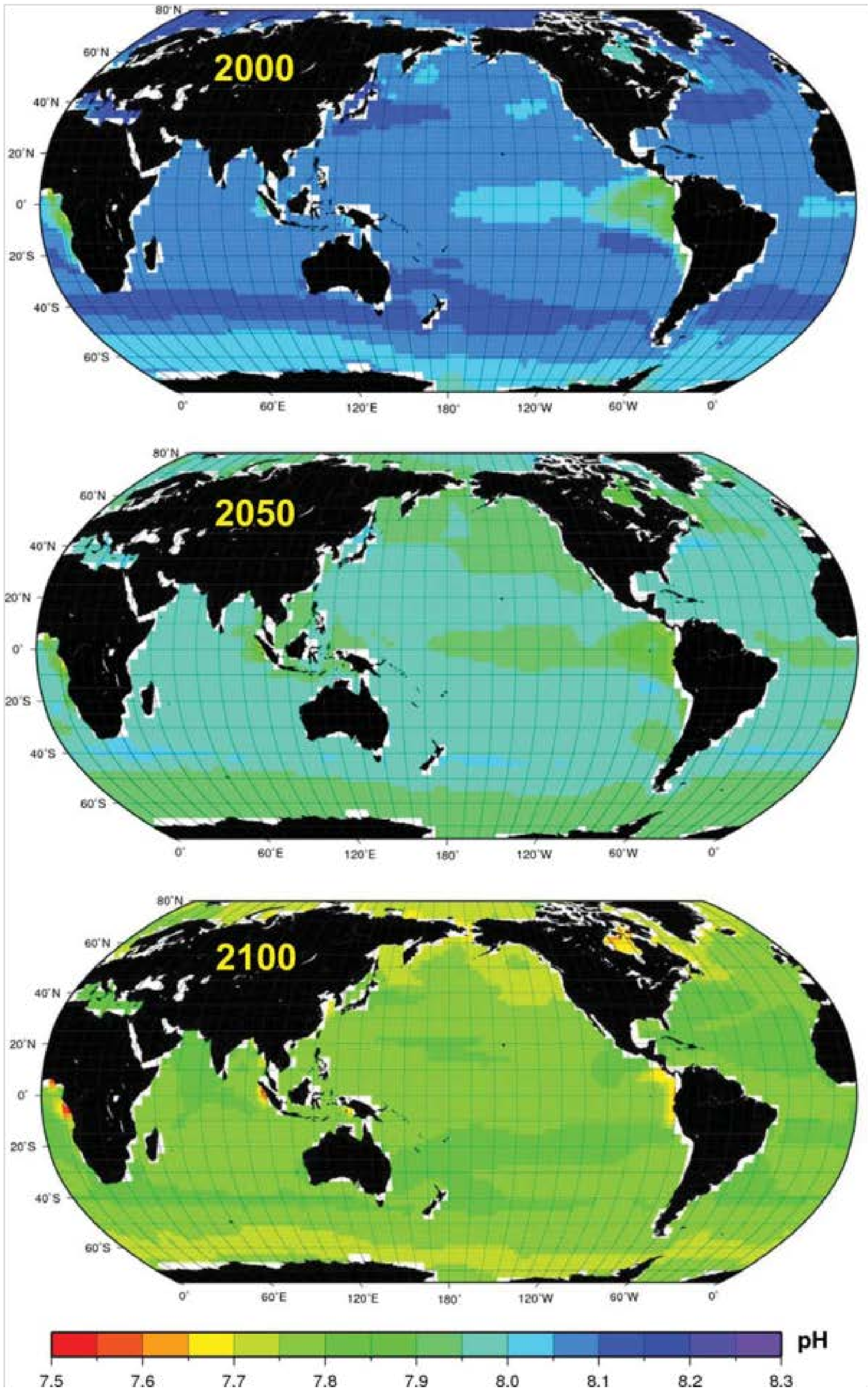

Figure 6.3. Model projections of global patterns in decreasing surface pH to 2100. From the Canadian Earth System Model (source: Denman *et al.* 2011).

Kleypas *et al.* (2006) noted that the question of how decreased calcification rates affect biological functioning or organism survival has been largely unstudied, although it is currently a "hot topic". The question of how economically important cultured and wild bivalve populations will respond to present and projected acidification levels is not sufficiently well known and should be included in future studies in terms of; (1) calcification response, (2) organism response (lethal and sublethal impacts and adaptation), (3) ecosystem response, and (4) socio-economic response.

Generally, there is a higher "cost of living" for many organisms subjected to high CO_2 marine environment. Some of the most vulnerable species may be tiny, shell forming animals at the base of the food web, which provide food for many larger species. However, some shellfish commonly grown or harvested for human consumption, including oysters and sea urchins, are also at risk. Scientists are now conducting laboratory studies to "stress test" marine larvae (including oysters, abalone, sea urchins and other shellfish) at different CO_2 levels. Options for an organism faced with environmental stress, such as ocean acidification, include migration, acclimatization (tolerance), adaptation (which may take generations if possible at all), and extinction (Workshop on Ocean Acidification, 2010).

Available studies indicate that marine bivalve molluscs cannot tolerate $pH \leq 7.0$ and that sea-water $pH < 7.5$ is harmful for marine bivalves (Michaelidis *et al.*, 2005). The following review focuses mainly on the effects of the predicted declining pH trend within the current century (i.e. $pH > 7.5$). Studies on the effects of elevated pCO_2 (reduced pH) on commercial marine calcifiers have been confined to a relatively small mumber of species (Table 6.4) and there remain large gaps in knowledge of the physiological and ecological impacts (Kleypas *et al.* 2006). Mussels and oysters are the most common species studied and these, and other estuarine invertebrates, are exposed to large natural fluctuations in CO_2 levels and pH and to changes resulting from other human stressors. Estuarine waters are more susceptible to acidification because they are subject to multiple acid sources and are less buffered than marine waters. Estuarine species may therefore experience acidification sooner than marine species and past exposures to widely fluctuating conditions may result in estuarine species being better adapted to these changes than open-ocean species.

Table 6.4. Summary of commercial shellfish species responses to ocean acidification with emphasis on studies related to mean global pH predictions to year 2100.

Species	pH	Response	Reference
Mytilus edulis Crassostrea gigas (juvenile & adult)	7.4 to 8.2	Mussel calcification declined linearly with decreasing pH and shells dissolve at pCO2 values ~ pH 7.5. Oyster CR also declined linearly but at a lower rate.	Gazeau *et al.* (2007)
Crassostrea gigas	7.7 & 8.07	Effects on energy metabolism detected.	Lannig *et al.* (2010)
Crassostrea virginica (juveniles)	7.5 & 8.3	Significant increase in juvenile mortality rates, inhibition of shell and body growth, altered physiology and shell properties. Reduced survival.	Beniash (2010)
Mytilus edulis (small adults)	6.7 to 8.1	No shell growth at pH 6.7 and reduced at 7.1. Higher mortalities for smallest mussels.	Berge *et al.* (2006)
Mytilus edulis (adults)	6.7 to 7.8	Immune response (levels of phagocytosis) declined during 32 day exposure to acidified sea water.	Bibby *et al.* (2008)
Saccostrea glomerata (embryos)	~ 7.5 to 8.3	Increasing temperature and pCO_2 combined to significantly decrease fertilization success, leading to fewer veligers, increased abnormalities and smaller sizes.	Parker *et al.* (2009)
Saccostrea glomerata	7.6 to 8.1	With decreasing pH, survival of larvae decreased, and growth and development were retarded.	Watson *et al.* (2009)
Mytilus edulis (adults)	7.5 to 8.2	Calcification can be maintained at control rates at pH 7.5. Long term acclimation to elevated pCO_2.	Thomsen *et al.* (2010)
Mercinaria mercinaria (juvenile)	7.1 to 7.8	Maximum mortality of 11% at lowest pH and evidence of massive external shell dissolution in smallest size-classes.	Green *et al.* (2004)
Mercinaria mercinaria (juvenile)	pH not reported	Buffering of sediments with crushed shell reduces mortalities caused by aragonite undersaturated sediments.	Green *et al.* (2009)
M. mercenaria Argopecten irradians (larvae)	7.5 to 8.1	Thicker, more robust shells and faster growth at preindustrial CO_2 levels. Malformed and eroded shells at reduced pH.	Talmage & Gobler (2010)
M. mercenaria Argopecten irradians Crassostrea virginic (larvae & juvenile)	7.8 to 8.2	Larvae were substantially more vulnerable to elevated CO_2 than juvenile stages. The negative effects of CO_2 and temperature were additive for 2 species of larvae.	Talmage & Gobler (2011)
Mytilus edulis (larvae)	7.6 to 8.1	Effects on both hatching rates and D-veliger shell growth that could lead to decreased settlement success.	Gazeau *et al.* (2010)
Crassostrea virginica (juvenile)	7.4 to 8.3	Biocalcification declined significantly with pH reduction.	Waldbusser *et al.* (2011a)
Crassostrea virginica	7.2 to 7.9	Dissolution rates were significantly different among all 4 pH treatments. Lowering pH increased dissolution rate.	Waldbusser *et al.* (2011b)
Crassostrea virginica Crassostrea ariakensis (larvae)	7.8 to 8.2	Only the Eastern oyster showed shell loss and growth reduction. Contrary to previous expectations, both species demonstrated net calcification and growth when aragonite was undersaturated.	Miller *et al.* (2009)
Haliotis rufescens (larvae)	7.9 & 8.1	Decreased thermal tolerance for some developmental stages.	Zippay *et al.* (2010)
Chlamys farreri	7.3 to 8.1	Calcification and respiration significantly declined as pH decreased.	Mingliang *et al.* (2011)
Pinctada fucata	7.6 to 8.1	Signs of malformation and/or dissolution in shells and decrease in shell strength	Welladsen *et al.* (2010)
Pinctada fucata	7.6 to 8.1	no significant difference in the number of byssal threads produced	Welladsen *et al.* (2011)

Gazeau *et al.* (2007) studies pCO_2 levels within the range of projected values (up to 1250 ppm in 2100). They showed that the calcification rates of *M. edulis* and *C. gigas* decline linearly with increasing pCO_2 and that mussel shells dissolved at pCO_2 values exceeding a threshold value of ~1800 ppm. It was projected that mussel and oyster calcification may decrease by 25 and 10%, respectively, by the end of the century. Lannig *et al.* (2010) demonstrated that CO_2 levels corresponding to expected ocean acidification scenarios are likely to interfere with the energy metabolism of *C. gigas*. Beniash (2010) showed that increasing pCO_2 in seawater within an environmentally relevant range for estuaries, and the associated decrease in pH, have negative effects on physiology, rates of shell deposition and mechanical properties of the shells of the oyster *C. virginica*. Bibby *et al.* (2008) investigated the immune response in mussels (*M. edulis*) exposed to acidified sea water and suggested that ocean acidification may impact the physiological condition and functionality of the haemocytes. Berge *et al.* (2006) showed that the growth of *M. edulis* at pH levels of 7.6 was not significantly different from growth at normal pH 8.1. Thomsen *et al.* (2010) also showed that calcification can be maintained by adult mussels at pH 7.5. These latter studies provide somewhat contradictory result (see Gazeau *et al.*, 2007) that may be explained by the mussels adaptation during the longer incubation period, respiratory production of pCO_2 in incubation chambers, which increases the capacity of the organism to fix CO_3^{2-}, and the use of less sensitive methods for detecting growth changes (Gazeau *et al.* 2007). The shells of *M. edulis* adults may also be protected by an intact periostracum, even under highly acidified conditions (Thomsen *et al.* 2010).

Bivalves exposed to CO_2 levels expected later this century have been observed to have shells that were malformed and eroded. According to Mingliang *et al.* (2011), the survival of the scallop *Chlamys farreri* is likely to be severely threatened in the next few centuries. They observed a 33% decrease in calcification rate with a decreasing pH from 8.1 to 7.9 and a further decrease to close to 0 at pH 7.3. CO_2 and O_2 respiratory rates were reduced by 14% and 11%, respectively, when pH decreased from 7.9 to 7.3. Increasing acidification also led to changes in metabolic pathways. Welladsen *et al.* (2010) also noted significant effects of reduced pH on pearl oyster (*Pinctada fucata*) shells (pH 7.6 to 7.8) but also showed no significant difference in the number of byssal threads produced under similar conditions (Welladsen *et al.*, 2011).

Larval and juvenile bivalves appear to be particularly sensitive to ocean acidification and high mortality rates have been linked to calcium carbonate dissolution (Green *et al.*, 2004; Fabry *et al.*, 2008). Talmage and Gobler (2010) examined the effects of the ocean's past, present, and future (21st and 22nd centuries) CO_2 concentrations on the growth, survival, and condition of larvae of two species of commercially and ecologically valuable bivalve shellfish (*Mercenaria mercenaria* and *Argopecten irradians*). Larvae grown under near pre-industrial CO_2 concentrations (250 ppm) displayed significantly faster growth and metamorphosis, higher survival and lipid accumulation rates, and displayed thicker more robust shells than individuals reared under modern day CO_2 levels. Talmage and Gobler (2011) further examined the effects of temperature and CO_2 concentrations on the growth, survival, lipid synthesis and condition of larvae and juveniles among bivalve shellfish (*M. mercenaria C. virginica* and *A. irradians*). The results indicate that larvae were substantially more vulnerable to elevated CO_2 than juvenile stages. Gazeau *et al.* (2010) demonstrated that the growth of *M. edulis* larvae is significantly affected by a decrease of pH to a level expected for the end of the century. Mussel larvae were able to develop a shell in seawater undersaturated with aragonite, however, the decreased hatching rate and shell growth suggested a negative impact of ocean acidification on survival, potentially leading to significant ecological and economical losses. Calcification rates of juvenile eastern oysters, *C. virginica*, measured at 3 pH levels, two salinities, and two temperatures, declined significantly with a reduction of ~0.5 pH units and higher temperature. However, changes in salinity may mitigate the decrease in biocalcification (Waldbusser *et al.* 2011). Miller *et al.* (2009) measured a 16% decrease in shell area for *C. virginica* larvae and a 42% reduction in calcium content between pre-industrial and end of the century pH levels. In contrast, *C. ariakensis* showed no change to either growth or calcification. In an experiment conducted by Watson *et al.* (2009) on the Sydney rock oyster *Saccostrea glomerata* larvae, the percentage of empty shells remaining from dead larvae decreased by 16% at pH 7.8 and by 90% at pH 7.6 indicating that the majority of empty shells dissolved within 7 days at pH 7.6. Zippay *et al.* (2010) showed that pH 7.9 caused a significant reduction in thermal tolerance for some abalone developmental stages (pretorsion and late veliger larvae), but not for others (posttorsion and premetamorphic veligers). These results indicated that larval stages were differentially sensitive to low pH conditions and this variability may play into the resilience of individual species to withstand environmental change in the longer term.

Parker *et al.* (2009) investigated the synergistic effects of ocean acidification (caused by elevations in the partial pressure of carbon dioxide pCO_2) and temperature on the fertilization and embryonic development of the economically and ecologically important Sydney rock oyster, *Saccostrea glomerata.* An increase in both parameters significantly decreased fertilization and led to fewer D-veligers, more abnormality and smaller sizes. They suggested that predicted changes in ocean acidification and temperature over the next century may have severe implications for the distribution and abundance of this, and other bivalve species.

Bivalves are a net source of dissolved CO_2 via respiration and the deposition of calcium carbonate in shell material, which induces a shift in the seawater carbonate equilibrium to generate CO_2. Using data on respiration and calcium carbonate production by the Asian clam, *Potamocorbula amurensis,* which is invasive to San Francisco Bay, Chauvaud *et al.* (2003) assessed their importance as CO_2 sources and provided compelling evidence that bivalve mollusks can markedly influence inorganic carbon cycling by generating CO_2 to the surrounding water. Lejart *et al.* (2012) studied respiration and calcification rates of *C. gigas* to estimate the effects of this exotic bivalve species on annual carbon budgets in the Bay of Brest, France. They suggest that the *C. gigas* populations increase CO_2 release to the atmosphere in coastal ecosystems and, consequently, contribute to the global warming that facilitates the northerly spread of this invasive species (see above). Increasing seawater temperature will hypothetically lead to increased respiration rates and therefore accentuate the effect of increasing pCO_2. This biogenic CO_2 source is increasing because of the continuing global translocation of molluscs, their successful colonization of new habitats and rapidly growing aquaculture production (Chauvaud *et al.*, 2003). It follows that the expansion of high-density bivalve aquaculture could have a substantial influence on the carbon cycle, particularly in coastal regions.

The studies to date generally suggests that the rise in pCO_2 can impact physiology, growth and biomineralization in marine calcifiers, threatening their survival and potentially leading to profound ecological and economic impacts in estuarine ecosystems. The available data also gives reason to speculate that recent declines in bivalve populations may be connected to ocean acidification. Two of the largest oyster hatcheries in the Pacific Northwest reported an 80% decline in production rates. It is suspected that wind-driven coastal upwelling events have exposed the bivalves to deep acidic waters (Miller *et al.*, 2009). Feely *et al.* (2008) observed that during a 2007 upwelling event, surface waters in a region near the California-Oregon border reached the low pH level of 7.75; exposing juvenile oysters to corrosive conditions. Coastal upwelling areas are some of the most productive regions for shellfish aquaculture.

6.5 Responsiveness of Existing Conservation and Protection Policies to Climate Change Issues

Cooley and Doney (2009) and Gazeau *et al.* (2007) both concluded that ocean acidification could lead to "substantial revenue declines, job losses, and indirect economic costs" as a result of loss of revenues from shellfish and their predators. Daiju *et al.* (2011) estimated that the global and regional economic costs of production loss of molluscs due to ocean acidification could be over 100 billion USD. This assumes an increasing demand for molluscs with expected income growth. *Post hoc* mitigation strategies for minimizing anticipated ocean acidification impacts are limited (e.g. Green *et al.* 2009; sediment buffering). A EU report recently reviewed how European policy adapts to marine climate change. *The Water Framework Directive* (WFD) does not directly respond to the effects of climate change, but aims to obtain a "good status" of water bodies. This iterative management system, with 6 year cycles of monitoring, assessments, and planning, should be robust to responding to climate change effects. OSPAR Commission Contracting Parties will establish ways in which to incorporate both climate change and ocean acidification considerations into future work. The Assessment and Monitoring Committee (ASMO) is currently taking this work forward using the latest pan European overview of climate change, produced by the European Science Foundation as one starting point to critically evaluate future science needs and to identify the 'added value' OSPAR might provide in this area.

The *NATURE 2000* legislation, designed to protect the most seriously threatened habitats and species across Europe, also does not directly address climate change. However, directives listing the habitat types and organisms protected can adapt in response to scientific advice. Canadian and U.S. federal environmental laws (e.g. Oceans Act, Clean Air Act, Clean Water Act, and Coastal Zone Management Act), attempt to provide a similar degree of protection as in the EU legislation. An important concept of both *The Common Fisheries Policy* and the Canadian *Oceans Act* is the precautionary approach. This approach may be used to adapt policy to the anticipated consequences of climate change.

While it may be perceived that the global problem of ocean acidification cannot be addressed at the local level, Kelly *et al.* (2011) describe policy options by which local and regional governments, as opposed to federal and international bodies, can reduce "hot spots" of ocean acidification. They suggest several mitigation strategies and a focus on data collection and the development of biological water-quality standards for acidification to assess if a water body is impaired on the basis of biological indicators. This could lead to future regulatory revisions that would allow local governments to regulate the activities of local contributors to coastal acidification.

6.6 Summary and Recommendations

The cumulative findings of the research studies reviewed in this report suggest that current and future increases in temperature and CO_2 are likely to have significant negative consequences for shellfish aquaculture. 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. The anticipated pathways leading to global warming and ocean acidification effects on shellfish aquaculture are summarized in Figure 6.4. Key interlinked global warming variables that can impact shellfish aquaculture include advection, vertical mixing, convection, turbulence, light, rainfall, fresh-water run-off, evaporation, oxygen concentration, pH, salinity, and nutrient supply. Changes in storm tracks, winds, rainfall, evaporation, sea ice, and river run-off will affect ocean currents, ocean fronts, and upwelling and downwelling, which, in turn, will profoundly affect the distribution and production of marine ecosystems at all levels, from plankton to fish. The most vulnerable industries, settlements and societies from climate change are likely to be those near the coast. Coastal community economies are closely linked with marine resources and are projected to be exposed to high risks from weather change, sea level rise and ocean acidification. An increase in freshwater run-off due to enhanced precipitation may require a shift from marine to more brackish water aquaculture species. The combination of an accelerating sea level rise and a possible increase in the frequency and intensity of storms will severely increase the risk of loss of sedimentary coastal marine habitats supporting intertidal shellfish aquaculture operations.

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.

Information gaps in our state of knowledge on climate change and ocean acidification impacts hamper the development potential solutions to the problems that will be faced by shellfish hatcheries, growers, and harvesters. Further studies are critically needed to determine the range of sensitivities, tolerance and adaptation potential of a wide range of aquaculture species to elevated temperatures and reduced pH in the future oceans ocean and potential synergistic effects. Of particular importance is improving research capacities to assess a species genetic adaptation potential to the predicted long-term climate change trends.

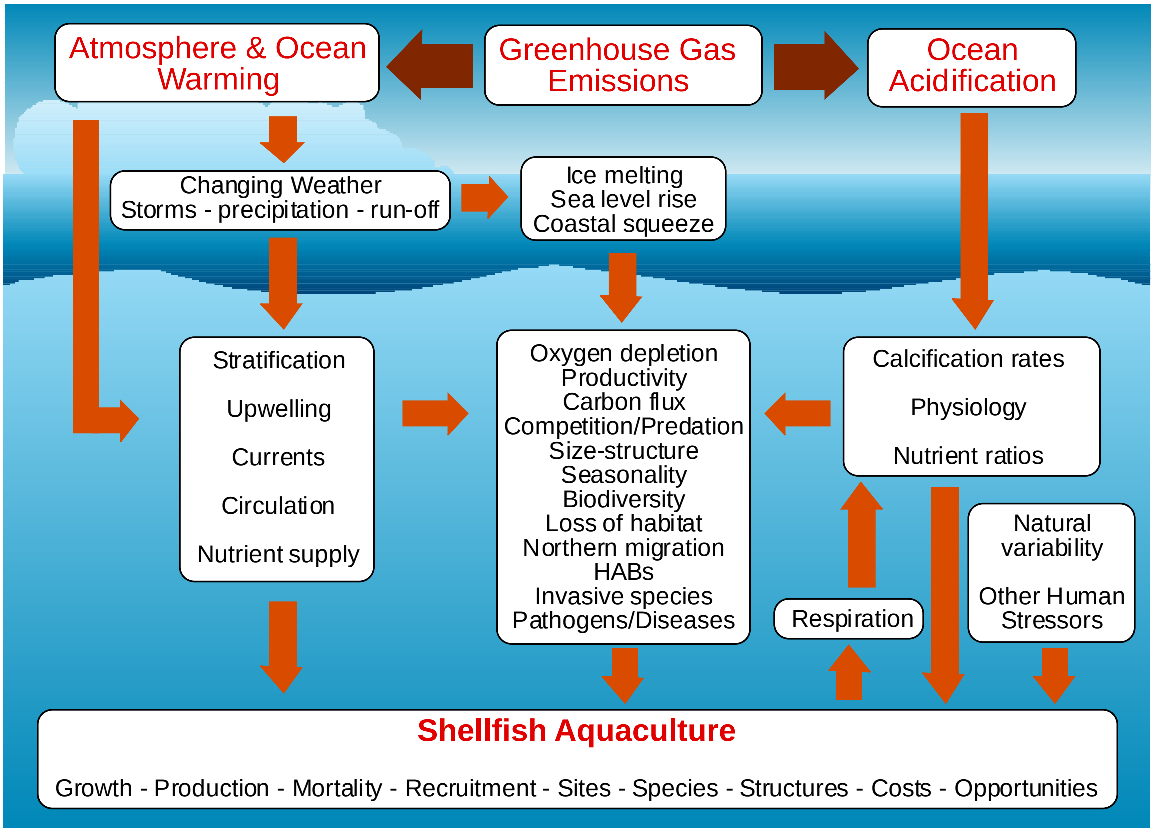

Figure 6.4. Examples of the pathways of effect of global warming and ocean acidification on ocean ecosystems and shellfish aquaculture.

Recommendations (SCICOM, WGEIM, WGFCCIFS, SSICCME)

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:

- determine sensitivities to perturbations under ecologically relevant conditions (i.e. exposed to predicted food web interactions);
- identification of the cumulative effects of warming and acidification;
- assess the capacity of key species to acclimate and/or genetically adapt to related modifications of their environment;
- given that climate change scenarios vary across ICES countries (temperature, precipitation, storms, deep water upwelling of acidic water…), assess regional susceptibilities for aquaculture impacts and the socio-economic consequences;
- development of decision-making processes for mitigation of shellfish aquaculture impacts and a proactive strategy for adaptation.

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7 Develop a workplan for new Terms of Reference (ToR e)

In order to develop a workplan for new Terms of Reference the Emerging Shellfish Aquaculture Issues and Related Science Advisory Needs reported on since 2007 were revisited. Shellfish culture is one of the major sectors of World Aquaculture, usefully situated at the lowest in the food chain, in which temperate countries and Europe specially play a dominant role. However, some new risks affect the sustainability of this sector essential for food delivery but also social and ecological services provided. Although the ToRs aim at applied results (mitigation, restoration, improved regulations), it needs to be scientifically based to be operative. In addition, a multidisciplinary approach including husbandry, ecology, diseases and genetics is needed. The numerous scientific results published on each factor have to be mobilized and adapted to the context of shellfish culture. Above all, any effect from shellfish culture or impact on shellfish cultivated in the wild, occurring from climate change, biological infestations or changes in culture practices, cannot be isolated, but interferes with lot of processes and feedbacks inside the entire ecosystem. So, in shellfish culture, ecology should be the key scientific discipline embracing different husbandry studies, like pathology or genetics. In our view the following subjects need attention through ToRs.

Environmental remediation through shellfish culture

Nutrient trading or bio-extraction as a mitigation measure for coastal eutrophication is a relatively new topic that is gaining considerable support from different industries and regulators. It entails trades between companies discharging excess nutrients to coastal waters (e.g. fertilizer run-off and organic waste discharge) and aquaculture farms that produce shellfish that can help to moderate phytoplankton concentrations act as a nutrient sink when harvested. E.g. water transparency is an important parameter included in the Water Framework Directive. This gives added value to shellfish aquaculture and increases shellfish production. However, there are still unresolved questions such as: how efficient is it, to what extend do shellfish act as nutrient sinks relative to the nutrient supplies, deposition of feces retains nutrients; are the right nutrients extracted (nitrogen versus phosphorus); what is the relation between nutrient flow and extraction rate; are there contaminants associated with the nutrient inputs that would affect the production and marketability of cultured shellfish; social questions such as who pays the costs; and under what circumstances is this trading scheme actually effective. The latter consideration is related to the site-specific nature of the relative importance of many environmental interactions with shellfish culture. It is important to balance the positive effect of the nutrient removal in the shellfish harvest with the potential negative effects of nutrient retention in the coastal zone that may occur as a result of the biodeposition activities of the introduced shellfish: local vs. global effects (e.g. Cranford *et al.*, 2007). In addition, the detrimental effects for aquaculture need to be considered. Anthropogenic contaminants may cause mortality or inconsumable products. The economic aspects in relation to nutrient trading quota need to be evaluated.

Acceptance of shellfish culture in Marine Protected Areas

The implementation of Marine Protected Areas can cause restrictions for shellfish farmers and conflicts between shellfish producers and environmental authorities. Spatial planning can help in these issues. However, this is rarely a joint process of all stakeholders. The fact that the definition of an MPA is not clear contributes to that. Furthermore, the benefits of MPA's to aquaculture are often not communicated. E.g. shellfish produced in an MPA might provide a better image (certification). The WGMASC can review guidelines such as Natura 2000, and compare the implementation in different ICES countries, identify differences between different types of MPAs and identify different management strategies, potential gaps between ambition and reality, and evaluate how knowledge on impact of shellfish aquaculture is used in different countries. E.g. in Northern Ireland *Modiolus modiolus* reefs need to be restored. However, baseline information on past occurrence is lacking. What criteria and thresholds are used to judge effects? WGMASC can provide science-based suggestions for thresholds, and evaluate the present use.

Sustainability Certification for cultured shellfish

Sustainability issues related to consumption of cultured shellfish receive a lot of attention presently. In response to consumer requests for organic and sustainable products, certification of cultured shellfish is starting. E.g. you have the Marine Stewardship Council, Aquaculture Stewardship Council, organic aquaculture, Label Rouge that indicates where the product comes from. Shellfish make an excellent candidate for an organic product as it does not need input of feed other that naturally occurring phytoplankton and can be produced locally. In addition, cultured shellfish do not only represent a valuable food product, during their life in the coastal zone, they also have a role in ecosystem services such as reducing nutrients in the water column and acting as a carbon sink. Furthermore, shellfish cultivation can enhance alternative livelihoods' in rural areas and provide social welfare. However, shellfish cultivation can have adverse effects on the ecosystem, such as bottom disturbance when dredging for seed (or harvest), enhanced deposition of organic material in local areas and reduction of the carrying capacity for other filter feeding organisms. A variety of organisations use different standards for organic certification. These need to be evaluated and unresolved questions (such as the role of shellfish in ecosystem services) need to be identified and addressed. To be able to judge the quality of the different labels WGMASC could recommend on comprehensiveness. What criteria, indicators and thresholds are used? Is the ecosystem perspective taken into account? The public needs to understand the differences. In addition, different countries have different interests in sustainability. The added value should be accepted. Some countries can use it as a trading barrier.

Restoration and augmentation of wild and cultured shellfish populations

Restoration of cultured shellfish populations is practiced in the United States for the American oyster. In France, oyster farmers faced with oyster mortalities consider restocking *Crassostrea gigas* from Japan as a means to genetically rejuvenate the population, in spite of lack of scientific proof. Identification of the right conditions for restocking is necessary. E.g. the scallop fishery in "Rade de Brest" (France) is largely dependent on hatchery production and restocking because the wild stock never recovered from severe depletion after 1963 cold winter, and following competition with *Crepidula*. Furthermore, development of a protocol is needed. Restoration, or rebuilding of spawning biomass for aquaculture purposes may be a solution for the European oyster *Ostrea edulis*. This species became extinct in a number of areas as a result of human activities. The Belgian oyster beds around the Hinderbanken were completely depleted by fishermen around 1870. This was due to the introduction of steamships which are capable of faster oyster harvest and transport (Slab-binck B., Verschoore K., Van Gompel J., Hugenholtz E. 2008. Natuurgebieden in de Noordzee voor Natuur en Mensen (in Dutch), 22p). It is a high valued species for fisheries and aquaculture. Restoration of the native population may not only benefit aquaculture, but it can also increase the value of the ecosystem. For *O. edulis* in *Bonamia* infested areas it needs to be investigated if a *Bonamia* resistant stock can be used. This is the subject of an EU project called OYSTERECOVER (http://oysterecover.eu/). In addition, socio-economic issues such as who will pay the restoration need attention.

Mitigating the anthropogenic, biological and environmental risks to the sustainability of mollusc aquaculture

The recent mass mortalities in Pacific oysters (*Crassostrea gigas*) raise a number of issues on the role of environment (e.g. climate change), emerging diseases and farming practices in shellfish aquaculture. These include: the rising role of hatcheries in the supply of seed; genetic improvement by selection (domestication, interactions with wild stocks); the positive and negative aspects of the increasing use of triploid seed; innovative techniques of culture, and increased stocking densities. The development of markets and trade also augment transfers between sites and countries, despite the presence of statutes developed to control the spread of certain diseases. Emerging diseases, indigenous and non-indigenous invasive species (predators, fouling, competitors) are also developing issues, possibly related to climate change, poor hygiene and husbandry, or associated with transfers of shellfish, seawater or fomites.

A better understanding of relationships, improved practices, efficient management and sound policies would help to evaluate and mitigate the role of different and often interacting factors. For example, it will be important to understand the role of disease surveillance and prevention, whether biosecurity plans and control measures are effective, how animal husbandry may be improved, whether biological control is an option, whether restocking with resistant strains developed through selective breeding programs can solve some of the problems, the genetic implications and whether eradication is feasible.

The following topics of shellfish aquaculture that affect mortalities and more generally yields, costs and economic profitability across shellfish species need to be addressed: effects of global change on shellfish culture, the introduction and and transmission of diseases, hatchery production, selective breeding, restocking and genetic implications, predation, fouling, competition for space or food, methods of surveillance, mitigation, biological controls and regulation. For this, cooperation will be sought with the Working Group on Environmental Interactions of Mariculture (WGEIM) for fouling aspects, the Working Group on Pathology and Diseases of Marine Organisms (WGPDMO) for epidemiological aspects, the Working Group on Application of Genetics in Fisheries and Mariculture (WGAGFM) for genetic aspects and with the Study Group on Socio-Economic Dimensions of Aquaculture (SGSA) for economic profitability.

8 Collaborate with WGEIM to discuss how to revitalize the issue of sustainability in aquaculture (ToR f)

Discussion issues:

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

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

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

Joint meeting between WGEIM and WGMASC

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

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

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

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

Thus, SCICOM has tasked the WGMASC and WGEIM to collaborate to develop a plan to establish a mechanism to develop an EG on "sustainability in aquaculture" to address the above issues. Ideally, a process would be developed so that clear requests for advice would be formulated by member states so that clear risk assessments could be undertaken by some form of EG or management structure of EGs on sustainability. To this end, the EGs held joint sessions within a joint meeting of the two groups in March 2012 in Sopot, Poland. After lengthy discussions, it was agreed to, as a first step, develop a list of country-specific priorities with respect to sustainability in aquaculture. A table was thus developed listing identified issues that will be circulated to member nations to gauge their level of concern and knowledge of the identified issues (see Annex 5). Second, a table of pros and cons of various management structures (see Table 7.1) of the existing EGs, creation of a new or multiple new EGs or transformation of existing ones was developed and debated on the joint sessions. It was hoped that this would guide the decision as to the most logical way forward to better address issues surrounding sustainability in aquaculture. Third, a note was drafted to send to member countries to solicit requests for science advice within the scope of knowledge of the EG(s); (see Annex 6). It is anticipated that requests coming directly from member countries will focus a portion of future ToRs for the group(s), specifically with respect to the development of risk assessments for various issues relating to the sustainability of various aspects of aquaculture. It also anticipated that some ToRs will remain that will be member-driven to meet individual member's needs.

Debate on the potential management structures to ensure that issues relating to sustainability in aquaculture and that a critical mass of people with experience related to fish culture would participate in the process resulted in 3 possible scenarios. These are listed in order of preference based on our deliberations (see Table 7.1). About 90% of the attendants to the meeting in Sopot support the first option, but the SSGHIE will have final say on the ultimate management structure. The WGMASC members present at the meeting are concerned that option one for the new structure (one large group on Sustainable Mariculture) will result in abolishment of the WGMASC group as well as reduce the capacity to provide advice on shellfish aquaculture issues. They feel that the WGMASC is functioning well with good attendance, work on ToRs that provide advice and that result in peer reviewed papers. In addition, the size of the group allows meeting at small institutes. Merging with WGEIM into a group that also works on fish and possibly other mariculture organisms will broaden the topics to be worked on in the limited time available. Science groups should be able to focus and you may lose critical mass, because many WGMASC members will not be able to attend the new group due to national limits on participation. Furthermore, this may be less attractive for researchers, as one of the benefits of going to an ICES EG meeting is to meet with people working in the same field.

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

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

Table 7.1. Retained options for new EG(s) to ensure that sustainability issues are adequately addressed.

Options	Pro	Con
Start a single new group on sustainable mariculture and finish both EIM and MASC	Attract new fish people and new questions for advice Interaction between shellfish and finfish people Room for other organisms (algae, sea cucumbers)	Less members for total group because of limitations placed on numbers of participants by some countries Dilution of issues not related to sustainability Group may become too big (difficult to manage and difficult to find venues) Lose momentum in a well-functioning EG (MASC) Attracting additional fish experts may be problematic (many present members shellfish experts) The influence of the EGs within ICES may be reduced as only a single EG will report and raise issues
Start two new groups, one on sustainable shellfish mariculture and one on sustainable finfish mariculture and finish both EIM and MASC	Attract new fish people and new questions for advice More interaction between former EIM and MASC members working on shellfish No overlap between groups Other groups of organisms can be included when names are adjusted (e.g. vertebrates/invertebrates and plants) The influence of the EGs within ICES will be retained as two separate EGs will report and raise issues	Less shellfish members for total group because of limitations placed on numbers of participants by some countries Less interaction between fish and shellfish people What to do with other organisms and IMTA? Dilution of issues not related to sustainability
Keep it as it is, but hold joint meetings every second year	No problem with number of members per country Keeps synergies developed within current groups The influence of the EGs within ICES will be retained as two separate EGs will report and raise issues	Low attendance by finfish people in EIM over past few years Overlap between EIM and MASC

9 Report to SSGHIE on plans to promote cooperation between EGs covering similar scientific issues (ToR g)

At the 2010 meeting WGMASC made a table of the SSGHIE expert groups (and more widely) identifying those where there may be potential for collaborative activity in the future. In 2011 and 2012 the table was reviewed and modified (Table 8.1). Since cooperation with WGEIM is discussed in chapter 7 of this report it is left out of the table.

Table 8.1. Overview of EGs with which WGMASC envisage possible future interactions.

	Interested in joint activity?	Joint meeting potential?
SGSA	Y	Y
WGPDMO	Y	N
WGAGFM	Y	N
WGICZM	Y	N
WGITMO	Y	N
WGHABD	Y	N
WGFCCIFS	Y	N
BEWG	Y	N
EuroShell	Y	N

WGMASC sees a need for a joint meeting with the Study Group on Socio-Economic Dimensions of Aquaculture (SGSA), because many of the shellfish aquaculture issues have a socio-economic dimension.

The Working Group on Introductions and Transfers of Marine Organisms (WGIMTO) has produced risk assessments on transfer of organisms that have been of relevance to WGMASC. In 2011 we invited Laurence Miossec of WGIMTO to help us with the ToR on *Aquaculture transfers between sites/countries –impact on wild stock*.

WGMASC regularly refers to documents from the Working Group on Pathology and Diseases of Marine Organisms (WGPDMO) and sent recommendations to them. Common issues are climate change, transfer of shellfish seed / seed quality. There is potential to swap experts between groups when relevant ToRs arise.

Joint activities, such as submitting a Theme Session for the Annual Science Conference in Bergen 2012 (proposal was not granted), were identified with WGPDMO and the Working Group on Application of Genetics in Fisheries and Mariculture (WGAGFM).

The Working Group in Integrated Coastal Zone Management (WGICZM) is relevant to WGMASC, particularly sustainability indicators and Marine Protected Areas. WGMASC deals with aquaculture aspects of ICZM.

There is potential for interaction with the Working Group on Harmful Algal Bloom Dynamics (WGHABD) on impacts of HAB toxins on cultured shellfish.

WGMASC is interested in outputs on climate change / aquaculture issues from the joint PICES/ICES Working Group on Forecasting Climate Change Impacts on Fish and Shellfish (WGFCCIFS).

There is common ground between the Benthic Ecology Working Group (BEWG) and WGMASC on benthic interactions with shellfish farming.

The EAS group EuroShell is looking at aspects of shellfish culture and has close interaction with WGMASC members.

Summarising we see three options for cooperation:

- When there is a clear overlap in ToRs we should have a meeting with a one-day overlap. An example of this is the joint WGMASC/WGEIM meeting held in 2010 in Galway.
- When WGMASC is dealing with a ToR that needs expertise of other another Expert Group, we invite a member of this group, e.g. WGIMTO in 2011.
- Our expertise on Marine Shellfish Culture can be helpful for other working groups, e.g. SGSA or WGICZM. Distributing our reports directly to those groups may stimulate cooperation.

Annex 1: List of participants

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Annex 2: Agenda

AGENDA ICES WGMASC 2012 Annual Meeting

Institute of Oceanology Polish Academy of Sciences, 55 Powstańców Warszawy Street, Sopot, Poland

Tuesday 20 March (Joint meeting with WG EIM)

09:00 Welcome from IO PAS by Prof. Janusz Pempkowiak, Director and house-keeping information from Roman Wenne

Introductory round and adoption of the agenda

Presentation of Plan for new Expert Group on Sustainable Aquaculture by Eric Olsen (chair SSGHIE)

Discussion on Plan for new EG Sustainable Aquaculture (ToR f)

10:30 *Health Break*

11.00 Continue discussion on Plan for new EG Sustainable Aquaculture (ToR f)

12:30 **Lunch**

13:30 **(WGMASC meeting)** Introductions and update on ICES activities – Pauline Kamermans

- Adoption of agenda
- General discussion of ICES activities
- Publications (see titles below)
- Discussion on ToRs
- Plenary to develop work plan, identify subgroups, subgroup leaders and rapporteurs
- ToR b*: Site selection criteria in molluscan aquaculture*
- ToR c: *Aquaculture transfers between sites/countries –impact on wild stock*
- ToR d: *Effect of climate change on shellfish aquaculture*

15:00 *Health Break*

15:30-18.00 ToR subgroup sessions

Wednesday 21 March

09:00 Reconvene ToR subgroup sessions

10:30 *Health Break*

11:00 Continue ToR subgroup sessions

12:30 **Lunch**

13:30 Continue ToR subgroup sessions

15:00 *Health Break*

15:30 Plenary discussion on ToR g: *Collaboration with other EGs in relation to the ICES Science Plan*

16:00-18.00 Plenary discussion on ToR a: *Emerging shellfish aquaculture issues and science advisory needs*

Dinner offered by our host

Thursday 22 March

09:00 Plenary – Discussion on Plan for new EG Sustainable Aquaculture (ToR f)

Drafting of recommendation to SCICOM on

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

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

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

10:30 *Health Break (presentation by Peter Cranford on IMTA research in Canada)*

11.00 Continue Discussion on Plan for new EG Sustainable Aquaculture (ToR f)

12:30 **Lunch**

13:30 Continue Discussion on Plan for new EG Sustainable Aquaculture (ToR f)

14.00 Reconvene ToR subgroup sessions

15.00 *Health Break*

15:30-18.00 Continue ToR subgroup sessions and finish 1st draft

Friday 23 March

09:00 Plenary Session:

- ToR e: *Develop a workplan for new Terms of Reference*
- Review and discuss 1st draft of WGMASC report (any publications?)
- Discussion and drafting of recommendations

10.30 *Health Break*

11.00 Plenary Session (cont.):

- Prepare Executive Summary
- Discussion on Theme Session for Annual Science Conference in 2013
- Date and location of the next meeting

12.00 Meeting Adjournment

12:30 **Lunch**

14.00 Excursion to Gdansk: old town and the Central Maritime Museum

Annex 3: WGXXX (new EG) terms of reference for the next meeting

The Working Group on XXX (WGXXX), chaired by NAME, Country, will meet in Palavas, France, 18–22 March 2013 (TBA) to:

a) Identify emerging shellfish 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 briefly highlight new and important issues that may require additional attention by the WGMASC and/or another Expert Group as opposed to providing a comprehensive analysis;

b) Review the state of the knowledge on environmental remediation through shellfish culture;

c) Review the state of knowledge on acceptance of shellfish culture in Marine Protected Areas;

d) Review the state of knowledge on sustainability certification for cultured shellfish;

e) Review the state of knowledge on restoration and augmentation of wild and cultured shellfish populations;

f) Review the state of knowledge on mitigating the anthropogenic, biological and environmental risks to the sustainability of mollusc aquaculture.

WGXXX will report by DATE 2013 (via SSGHIE) for the attention of SCICOM.

Supporting Information

Priority	WGMASC is of fundametal importance to ICES environmental science and advisory process and addresses many specific issues of the ICES Strategic Plan and the Science Plan. It concerns the aquaculture sector whose growth may be considered insufficient in Europe and North America. The current activities of this Group will lead ICES into issues related to the ecosystem effects of the continued rapid development of shellfish aquaculture, especially with regard to the implications of changing environmental conditions on shellfish cultures Consequently, these activities are considered to have a high priority.
Scientific justification	Term of Reference a) For the WGMASC to be responsive to the rapidly changing science advice needs of aquaculture and environmental managers, important emerging shellfish aquaculture issues need to be rapidly identified and screened for potential science advisory needs to maintain the sustainable use of living marine resources and the protection of the marine environment. The intention is for this activity to flag issues that may require future attention and communication between one or several ICES Expert Groups. The Chair of the WGMASC will cross-reference all work with SCICOM and relevant Working Groups. Term of Reference b) Nutrient trading or bio-extraction as a mitigation measure for coastal eutrophication is a relatively new topic that is gaining considerable support from different industries and regulators. It entails trades between companies discharging excess nutrients to coastal waters (e.g. fertilizer run-off and organic waste discharge) and aquaculture farms that produce shellfish that can help to moderate phytoplankton concentrations act as a nutrient sink when harvested. E.g. water transparency is an important parameter included in the Water Framework Directive. This gives added value to shellfish aquaculture and increases shellfish production. However, there are still unresolved questions such as: how efficient is it, to what extend do shellfish act as nutrient sinks relative to the nutrient supplies, deposition of feces retains nutrients; are the right nutrients extracted (nitrogen versus phosphorus); what is the relation

between nutrient flow and extraction rate; are there contaminants associated with the nutrient inputs that would affect the production and marketability of cultured shellfish; social questions such as who pays the costs; and under what circumstances is this trading scheme actually effective. The latter consideration is related to the site-specific nature of the relative importance of many environmental interactions with shellfish culture. It is important to balance the positive effect of the nutrient removal in the shellfish harvest with the potential negative effects of nutrient retention in the coastal zone that may occur as a result of the biodeposition activities of the introduced shellfish: local vs global effects (e.g. Cranford *et al.* 2007). In addition, the detrimental effects for aquaculture need to be considered. Anthropogenic contaminants may cause mortality or inconsumable products. The economic aspects in relation to nutrient trading quota need to be evaluated. The Chair of WGMASC will cross-reference all work with SCICOM and relevant Working Groups.

Term of Reference c)

The implementation of Marine Protected Areas can cause restrictions for shellfish farmers and conflicts between shellfish producers and environmental authorities. Spatial planning can help in these issues. However, this is rarely a joint process of all stakeholders. The fact that the definition of an MPA is not clear contributes to that. Furthermore, the benefits of MPA's to aquaculture are often not communicated. E.g. shellfish produced in an MPA might provide a better image (certification). The WGMASC can review guidelines such as Natura 2000, and compare the implementa-tion in different ICES countries, identify differences between different types of MPAs and identify different management strategies, potential gaps between ambition and reality, and evaluate how knowledge on impact of shellfish aquaculture is used in different countries. E.g. in Northern Ireland Modiolus modiolus reefs need to be restored. However, baseline information on past occurrence is lacking. What criteria and thresholds are used to judge effects? WGMASC can provide science-based suggestions for thresholds, and evaluate the present use. The Chair of WGMASC will cross-reference all work with the Chairs of the WGEIM, WGPDMO and WGITMO.

Term of Reference d)

Sustainability issues related to consumption of cultured shellfish receive a lot of at-tention presently. In response to consumer requests for organic and sustainable products, certification of cultured shellfish is starting. E.g. you have the Marine Stew-ardship Council, Aquaculture Stewardship Council, organic aquaculture, Label Rouge that indicates where the product comes from. Shellfish make an excellent candidate for an organic product as it does not need input of feed other that naturally occurring phytoplankton and can be produced locally. In addition, cultured shellfish do not only represent a valuable food product, during their life in the coastal zone, they also have a role in ecosystem services such as reducing nutrients in the water column and acting as a carbon sink. Furthermore, shellfish cultivation can enhance alternative livelihoods' in rural areas and provide social welfare. However, shellfish cultivation can have adverse effects on the ecosystem, such as bottom disturbance when dredging for seed (or harvest), enhanced deposition of organic material in local areas and reduction of the carrying capacity for other filter feeding organisms. A variety of organisations use different standards for organic certification. These need to be evaluated and unresolved questions (such as the role of shellfish in ecosystem services) need to be identified and addressed. To be able to judge the quality of the different labels WGMASC could recommend on comprehensiveness. What criteria, indicators and thresholds are used? Is the ecosystem perspective taken into account? The public needs to understand the differences. In addition, different countries have different interests in sustainability. The added value should be accepted. Some countries can use it as a trading barrier.The Chair of WGMASC will cross-reference all work with the Chair of the WGEIM.

Term of Reference e)

Restoration of cultured shellfish populations is practiced in the United States for

	the American oyster. In France, oyster farmers faced with oyster mortalities consider restocking Crassostrea gigas from Japan as a means to genetically rejuvenate the popu-lation, in spite of lack of scientific proof. Identification of the right conditions for re-stocking is necessary. E.g. the scallop fishery in "Rade de Brest" (France) is largely dependent on hatchery production and restocking because the wild stock never re-covered from severe depletion after 1963 cold winter, and following competition with Crepidula. Furthermore, development of a protocol is needed. Restoration, or rebuilding of spawning biomass for aquaculture purposes may be a solution for the European oyster Ostrea edulis. This species became extinct in a number of areas as a result of human activities. The Belgian oyster beds around the Hinderbanken were completely depleted by fishermen around 1870. This was due to the introduction of steamships which are capable of faster oyster harvest and transport (Slab-binck B., Verschoore K., Van Gompel J., Hugenholtz E. 2008. Natuurgebieden in de Noordzee voor Natuur en Mensen (in Dutch), 22p). It is a high valued species for fisheries and aquaculture. Restoration of the native population may not only benefit aquaculture, but it can also increase the value of the ecosystem. For O. edulis in Bonamia infested areas it needs to be investigated if a Bonamia resistant stock can be used. This is the subject of an EU project called OYSTERECOVER (http://oysterecover.eu/). In addition, socio-economic issues such as who will pay the restoration need attention. The Chair of WGMASC will cross-reference all work with SCICOM and relevant Working Groups. Term of Reference f) The recent mass mortalities in Pacific oysters (Crassostrea gigas) raise a number of issues on the role of environment (e.g. climate change), emerging diseases and farming practices in shellfish aquaculture. These include: the rising role of hatcheries in the supply of seed; genetic improvement by selection (domestication, interactions with wild stocks); the positive and negative aspects of the increasing use of triploid seed; innovative techniques of culture, and increased stocking densities. The development of markets and trade also augment transfers between sites and countries, despite the presence of statutes developed to control the spread of certain diseases. Emerging diseases, indigenous and non-indigenous invasive species (predators, fouling, competitors) are also developing issues, possibly related to climate change, poor hygiene and husbandry, or associated with transfers of shellfish, seawater or fomites. A better understanding of relationships, improved practices, efficient management and sound policies would help to evaluate and mitigate the role of different and often interacting factors. For example, it will be important to understand the role of disease surveillance and prevention, whether biosecurity plans and control measures are effective, how animal husbandry may be improved, whether biological control is an option, whether restocking with resistant strains developed through selective breeding programs can solve some of the problems, the genetic implications and whether eradication is feasible. The following topics of shellfish aquaculture that affect mortalities and more generally yields, costs and economic profitability across shellfish species need to be addressed: effects of global change on shellfish culture, the introduction and and transmission of diseases, hatchery production, selective breeding, restocking and genetic implications, predation, fouling, competition for space or food, methods of surveillance, mitigation, biological controls and regulation. For this, cooperation will be sought with the Working Group on Environmental Interactions of Mariculture (WGEIM) for fouling aspects, the Working Group on Pathology and Diseases of Marine Organisms (WGPDMO) for epidemiological aspects, the Working Group on Application of Genetics in Fisheries and Mariculture (WGAGFM) for genetic aspects and with the Study Group on Socio-Economic Dimensions of Aquaculture (SGSA) for economic profitability. The Chair of WGMASC will cross-reference all work with SCICOM and relevant Working Groups.
Resource	The research programmes which provide the main input to this group are

requirements	already underway, and resources are already committed. The additional resource required to undertake additional activities in the framework of this group is negligible.
Participants	The Group is normally attended by some 10–12 members and guests.
Secretariat facilities	None.
Financial	No financial implications.
Linkages to advisory committees	SCICOM
Linkages to other committees or groups	There is a working relationship with the WGEIM, SGSA, WGIMTO, WGPDMO, and the work is relavant to WGMPCZM.
Linkages to other organizations:	The work of this group is aligned with similar work in GESAMP, WAS, and EAS and numerous scientific and regulatory governmental departments in ICES countries.

Annex 4: Recommendations

RECOMMENDATION	ADRESSED TO
1. The WGMASC recommends that the ToRs identified at the meeting in Sopot (see Annex 3) will be included in the new EG to be started at the ASC in Bergen.	SCICOM
2. The WGMASC recommends to seek active involvement of other mariculture oriented EGs (apart from WGEIM) in the new EG.	SCICOM, SGSA, WGPDMO, WGAGMF
3. The WGMASC recommends that ICES considers a dedicated position in the Secretariat to promote and coordinate ICES activities with client organizations and member states in relation to mariculture.	SCICOM
4. The WGMASC recommends that 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 sensi-tive early life stages (for details see section 6.6).	SCICOM, WGFCCIFS, SSICCME

Annex 5: Overview of country-specific interests (I) and knowledge (K)

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

Interest

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

Knowledge

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

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

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

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

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

Annex 6: Letter to solicit requests for science advice on sustainable aquaculture

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

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

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

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

ICES is presently considering putting more emphasis on aquaculture suistainability and provision of advice, including the creation of an over-arching Group on Mariculture Sustainability.

Member states are encouraged to utilise ICES as an independent and efficient means to intergrate international mariculture research and provide advice through a large numbers of expert groups, symposia, and an Annual Science Conference. Also, ICES can be a prime source of scientific advice on the marine ecosystem to governments and international regulatory bodies that manage mariculture in the North Atlantic Ocean and adjacent seas. For some specific examples of the type of advice given in the past see table A6.1 and A6.2.

Table A6.1. Subjects worked on by WGMASC.

ToR subjects	Years
Development of hatcheries	2003–2005
Abnormal mortalities of shellfish	2003
Ecological factors affecting shellfish production	2003–2004
Sustainability of shellfish culture	2003–2004

Stress indices for shellfish to identify potential diagnostic tools	2003–2007
Performance indices for shellfish	2004–2005
Impacts of shellfish aquaculture activities in the coastal zone	2006–2009
Hatchery reared seed to enhance wild scallop fisheries	2006–2007
Emerging shellfish aquaculture issues	2007–2012
Bivalve aquaculture transfers between sites	2008–2012
Effect of climate change on shellfish aquaculture	2008–2012
Site selection criteria in molluscan offshore aquaculture	2010–2012

Table A6.2. Publications produced by WGMASC.

• Cranford P. J., P. Kamermans, G. Krause, J. Mazurié, B. Buck, P. Dolmer, D. Fraser, K. Van Nieuwenhove, F. X. O'Beirn, A. Sanchez-Mata, G. G. Thorarinsdóttir, and Ø. Strand. An Ecosystem-Based Approach and Management Framework for the Integrated Evaluation of Bivalve Aquaculture Impacts. Accepted by Aquaculture Environment Interactions.
• Fraser D., M. Brenner, F. Muehlbauer, M. Gubbins, K. Van Nieuwenhove, B. H. Buck, O. Strand, J. Mazurié, G. Thorarinsdottir, P. Dolmer, F. O`Beirn, A. Sanchez-Mata, P. Kamermans. Bivalve Aquaculture Transfers in Atlantic Europe Part I: transfer activities and legal background.
• Brenner M., D. Fraser, K. Van Nieuwenhove, F. O`Beirn, M. Gubbins, B. H. Buck, J. Mazurié, G. Thorarinsdottir, P. Dolmer, A. Sanchez-Mata, O. Strand, P. Kamermans. Bivalve Aquaculture Transfers in Atlantic Europe Part II: environmental impacts.