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Report of the Working Group on Marine Shellfish Culture (WGMASC)

5–8 April 2011

La Trinité-sur-Mer, France

International Council for the Exploration of the Sea

Conseil International pour l'Exploration de la Mer

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Executive summary

The ICES Working Group on Marine Shellfish Culture (WGMASC), chaired by Pauline Kamermans, held its ninth meeting in La Trinite sur Mer, France, on 4–8 April 2011. It was attended by 15 persons from 11 countries. The formal mandate and objectives of the meeting were to work on six ToRs and to discuss two manuscripts based on finished ToRs.

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 (Contributions of WGMASC to the Strategic Initiative on Coastal and Marine Spatial Planning (SICMSP) and ToR f (Collaboration with other EGs in relation to the ICES Science Plan) were addressed in a plenary sessions. The manuscripts are An Ecosystem-Based Framework for the Integrated Evaluation and Management of Bivalve Aquaculture Impacts for Aquaculture Environment Interactions and Bivalve Aquaculture Transfers in Atlantic Europe for Aquaculture International.

ToR a) Two new emerging issues were identified by the group: Impact of aquaculture in Marine Protected Areas and Emerging diseases, fouling and predators in shellfish aquaculture. It was decided to aim for a Theme Session on the second subject for the Annual Science Conference in Bergen. For this, cooperation will be sought with the Working Group on Environmental Interactions of Mariculture (WGEIM) for fouling aspects, Working Group on Pathology and Diseases of Marine Organisms (WGPDMO) for epidemiological aspects, and with the Working Group on Application of Genetics in Fisheries and Mariculture (WGAGFM) for genetic aspects. In addition, two emerging issues that were identified last year were revisited: Augmentation of cultured shellfish populations and Environmental remediation. In addition, several oyster growers from the area of La Trinité sur Mer were interested in the work of the WGMASC and a discussion was organised at the end of the meeting (Chapter 3).

ToR b) The collection and collation of data on offshore aquaculture continued, especially for ecological site-selection criteria. Further, an update on countries-specific information was conducted too. 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 off shore production concepts and cooperation in field tests of such a concept can improve the quality of the knowledge to the issue (Chapter 4).

ToR c) Potential effects and implications (both positive and negative) of the introduction and translocation of live shellfish from hatcheries and field sites to wild and cultured stocks are described. These include development of stock and new habitats; transfer of macro parasites and pests; transfer of biotoxins, cysts, larvae and eggs; transfer of micro parasites and diseases; transfer of human pathogenic agents bacteria and viruses; genetic effects of transfers; impact of transfer on biodiversity. Scientific tools to support policy decisions on cultured shellfish transfer issues and recommendations to farmers and policy makers are given (Chapter 5).

ToR d) Cumulative effects of climate change through changes in runoff of freshwater and contaminants, waves and coastal erosion, storm frequency and intensity, water temperature, oxygen levels, primary production, microalgal biodiversity, predators, parasites, diseases, the presence of nuisance species, ocean acidification etc. on shell-

fish aquaculture are expected. Knowledge is needed to more fully identify the threats and potential opportunities. The research effort on the effect of climate change on cultured shellfish species is largely in its infancy, but is increasing rapidly. Rather than continue to simply review project results as they become available, we recommend that the WGMASC focus future activities on the provision of advice on related research and management priorities. (Chapter 6).

ToR e) Contributions of WGMASC the Strategic Initiative on Coastal and Marine Spatial Planning can be providing examples and case studies. In addition, expertise of the group can be used when information is needed on where shellfish can be grown and what the environmental impacts of those activities are, and on decision support tools that can be used in spatial planning of aquaculture areas (Chapter 7).

ToR f) WGMASC sees three options for cooperation between EGs: When there is a clear overlap in ToRs we should have a meeting with a one-day overlap. When WGMASC is dealing with a ToR that needs expertise of other another Expert Group, we invite a member of this group. Our expertise on Marine Shellfish Culture can be helpful for other working groups. Distributing our reports directly to those groups may stimulate cooperation (Chapter 8).

1 Opening of the meeting

The ICES Working Group on Marine Shellfish Culture (WGMASC), chaired by Pauline Kamermans (Netherlands), held its ninth meeting in La Trinite sur Mer (France) on 4–8 April 2011 at Ifremer. It was attended by 15 persons from 11 countries (Annex 1). The meeting was opened at 9.00 am Tuesday 5 April with the host Joseph Mazurié giving housekeeping information and a welcome by Edouard Bédier, director of the station Ifremer of La Trinité sur Mer. The chair thanked the hosts for their hospitality. Three new people were welcomed in the group: one invited member from the Working Group on Introductions and Transfers of Marine Organisms WGIMTO (Laurence Miossec from France) and two new WGMASC members (Jeff Flimlin from the US and Rene Robert from France). The chair thanked the respective institutions of all participants for allowing time and money to join the meeting.

Other new members that recently joined WGMASC, but were unable to come to the meeting, are Luc Commeau and Marcel Frechette from Canada and Sandra Joaquim from Portugal. The only shellfish producing ICES country that is not represented in the WGMASC is Sweden. Efforts of the chair to attract a member from that country were not successful so far. The members from Norway and Denmark agreed to assist in this matter.

The chair gave a brief overview of ICES activities since the last WGMASC meeting. We had a successful Theme Session September 2010 in Nantes on "Synergies and conflicts of multiple uses of marine areas by using marine spatial planning" convened by Bela Buck and Gesche Krause. The next ASC in September 2011 will be held in Gdansk in Poland. There are no aquaculture related theme sessions. ICES welcomes sessions on that subject and urges us to think about one for the ASC in Bergen in 2012. Furthermore, a new Study Group on Socio-economic Dimensions of Aquaculture (SGSA) was started. The key motivation to start the study group on the socio-economic dimensions of aquaculture is the observation that while in many incidences the introduction of aquaculture was technically a success, socio-economic and cultural factors of the technology was not well-adopted by local communities and municipalities. The study group can be viewed as a timely opportunity to define the challenges of sustainable aquaculture development collectively across different scientific disciplines vis-á-vis endorsing the social dimension at various scales. Gesche Krause is chair and the group will meet 11–14 April in Bremen. It was agreed that close contact with the study group is desirable, since socio-economic topics often play a role in marine shellfish culture.

Two manuscripts on Terms of Reference that were closed in earlier years are in preparation:

Peter J. Cranford, Pauline Kamermans, Gesche Krause, Alain Bodoy, Joseph Mazurié, Bela Buck, Per Dolmer, David Fraser, Michael Gubbins, Kris Van Nieuwenhove, Adoración Sanchez-Mata, and Øivind Strand "An Ecosystem-Based Framework for the Integrated Evaluation and Management of Bivalve Aquaculture Impacts" To be submitted to 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" To be submitted to Aquaculture International.

During the meeting participants provided comments to the persons driving the publications (Peter Cranford and Matthias Brenner). The comments will be included in new versions that are presently prepared and will be submitted to the above mentioned journals soon.

2 Adoption of the agenda and appointment of rapporteurs

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. This year some new items were added to the agenda: short presentations on recent oyster mortality and herpes virus by Nathalie Cochennec (Ifremer) and David Fraser (Fisheries Research Service Marine Laboratory). In addition, Ifremer organised a discussion between WGMASC and French oyster farmers (see 3.2). And finally, Kris van Nieuwenhove gave a short presentation on a request related to DG Environment Regulations for Aquaculture in Natura 2000 areas.

A general discussion on plans for each WGMASC Term of Reference was held. The subgroup leader for ToR b (Site selection criteria in molluscan aquaculture) was Bela Buck. This ToR is in its second year. ToR c ('Aquaculture transfers between sites/countries - impact on wild stock' was started in 2008 together with a ToR on 'Aquaculture transfers between sites/countries – guidelines and records'. The guidelines and records part was finished in 2010 and is now in preparation as a manuscript (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" To be submitted to Aquaculture International). Since Matthias Brenner would be busy working on the manuscript, it was decided that David Fraser and Francis O'Beirn would be subgroup leaders for this ToR. The chair suggested to aim for completing ToR c, but during the meeting this proved to be too ambitious. ToR d (Effects of climate change on shellfish aquaculture) started in 2008 and was continued with Peter Cranford as the subgroup leader. As in other years it was decided to address ToR a (Identify emerging shellfish aquaculture issues and science advisory needs) in a plenary session with the chair as rapporteur. The group felt that contributions to ToR e (Contributions of WGMASC to the Strategic Initiative on Coastal and Marine Spatial Planning (SICMSP) and ToR f (Collaboration with other EGs in relation to the ICES Science Plan) could not be very substantial in comparison to the work done in 2010. Thus, it was decided to discuss these topics in plenary sessions. The chair reported on these ToRs. Before starting the work, the chair explained the use of the share drive to the new members.

During discussions of the ToR's it was concluded that the ToR's are linked together. E.g. the ToR d) on climate change is linked to ToR b) on site selection criteria and ToR c) on aquaculture transfer. These links were not specifically analysed during the meeting due to the tight work-schedule. A framework for a more systematically integration of ToR's and identification of significant links should be developed.

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)

3.1 Emerging shellfish aquaculture issues

Two new emerging issues were identified by the group:

Impact of aquaculture in Marine Protected Areas (MPA). 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 different management strategies, potential gaps between ambition and reality, and evaluate how is knowledge on impact of shellfish aquaculture used in different countries.

Emerging diseases, fouling and predators in shellfish aquaculture. The recent mass mortalities in oysters due to herpes virus started a discussion on the role of environment (climate change) and the role of hatcheries (debate between traditional and innovative farmers). In addition, there are emerging problems with nuisance organisms. Important questions are how to eradicate or control these organisms. Is biological control an option? What biosecurity plans and control measures are effective? What is the role of prevention, animal husbandry and surveillance? What socio-economic aspects of the issue can be identified? Can restocking with resistant strains solve some of the problems? What are the genetic implications of this? It was decided to aim for a Theme Session on this subject for the Annual Science Conference in Bergen. For this, cooperation will be sought with the Working Group on Environmental Interactions of Mariculture (WGEIM) for fouling aspects, Working Group on Pathology and Diseases of Marine Organisms (WGPDMO) for epidemiological aspects, and with the Working Group on Application of Genetics in Fisheries and Mariculture (WGAGFM) for genetic aspects. Joseph Mazurié will take the lead in formulation a Theme Session call for papers and Gef Flimlin and Pauline Kamermans will assist him in getting the right persons involved.

In addition, two emerging issues that were identified last year were revisited.

Augmentation of cultured shellfish populations. This can either be restocking or rebuilding of spawning biomass for aquaculture purposes, or restoration of shellfish populations as a tool to restore ecosystem services. Restoration of the habitat 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 and locations 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. Restocking 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 (Slabbinck *et al.*, 2008). It is a high valued species for fisheries and aquaculture. Restocking 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 a new EU project called OYSTERECOVER (http://oysterecover.eu/). In addition, social-economic issues such as who will pay the restoration need attention.

<u>Environmental remediation</u>. 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. This gives added value to shellfish aquaculture and increases shellfish production. However, there are still unresolved questions such as: to what extend do shellfish act as nutrient sinks relative to the nutrient supplies; 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 2012 a number of ToRs will be finished. Therefore, it was suggested to plan time at the 2012 meeting to develop a workplan for new ToRs. The above mentioned topics can be considered then.

References

Cranford *et al.* 2007. Influence of mussel aquaculture on nutrient dynamics in a nutrient enriched coastal embayment. Mar. Ecol. Prog. Ser. 347: 61-78

Slabbinck B., Verschoore K., Van Gompel J., Hugenholtz E. 2008. Natuurgebieden in de Noordzee voor Natuur en Mensen (in Dutch), 22p).

3.2 Discussion with French oyster farmers

Several oyster growers from the area of La Trinité sur Mer were interested in the work of the WGMASC and a discussion was organised at the end of the meeting. The following persons were present:

- Hervé JENOT, president of Regional Committee of shellfish farmers South Brittany;
- François CADORET, president of Sobaie (Union of Baie of Quiberon oyster farmers;
- Olivier MAHE, shellfish farmer;
- Christian DUCOS, shellfish farmer;
- François GOUZER, shellfish farmer;
- Yannick STEPHANT, shellfish farmer.

The chair gave a brief overview of the ToRs the group had worked on during the meeting. In addition, the different members of the working group introduced themselves and provided information on the shellfish species that are cultured in their respective countries. Then, the discussion focussed on a possible relation between work on tetraploid oysters at Rutgers University and the problems with herpes virus in France. In addition, different views on the desirability of the use of (triploid) hatchery spat were expressed by the farmers. And finally the relation between science (Ifremer) and industry (the farmers) was discussed. Jeff Flimlin gave an example from the US, where so called extension officers are charged with facilitating the relation between science and industry. In addition, Peter Cranford mentioned Canadian support of the state to farmers.

4 Review the state of the knowledge of 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 and growth and survival performances 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 operation on offshore shellfish farming, both for spat collection or for ongrowing 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

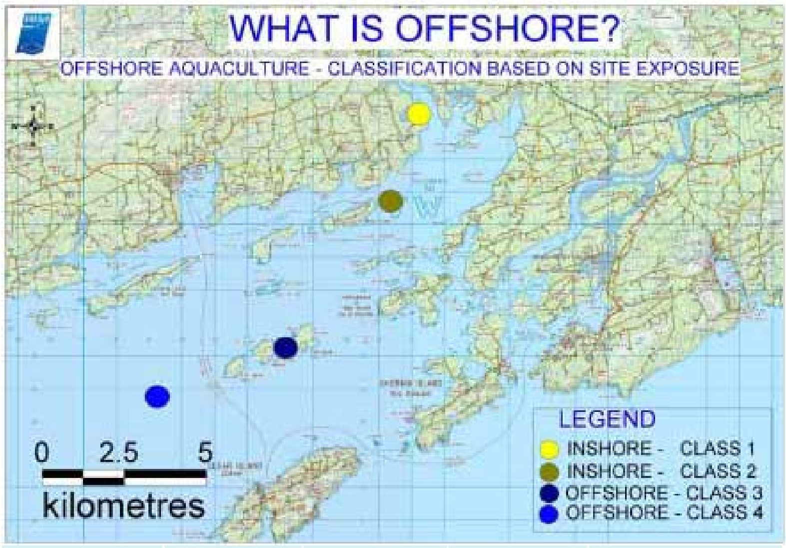
In the first year (2010) the topic of site-selection criteria with particular reference to offshore areas was defined. Further, the state of the art of offshore shellfish culture was reviewed as well as the various intentions to move off the coast into high energy environments in ICES countries. In addition, biological, technical, and economic records were reviewed with special focus on site-selection. This year (2011), the collection and collation of data continued, especially for ecological site-selection criteria.

Further, an update on countries-specific information was conducted too. ToR b) will be completed in year 3 (2012) with a final report including marine spatial planning and recommendations on scientific tools for decision support and of shellfish culture in offshore areas in general.

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

Offshore aquaculture (OA), also described as open ocean aquaculture (OOA), is a culture operation in a frequently hostile open ocean environment. Nowadays, there are various definitions on what is "real" offshore. In the implementation of strategies on 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 being a site which is beyond the 12 nautical mile zone of the coastal sea. However, for any aquaculture enterprise the term offshore is defined as being in a marine environment fully exposed to a wide range of oceanographic conditions (Ryan 2004), such as strong currents and swell as well as high waves. This increased exposure to higher wave energy is linked to distance from shore or lack of shelter from topographical features such as islands or headlands that can mitigate the force of ocean and wind-generated waves. Following Buck (2004), 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 from case to case. Figure 4.1 will help to classify if certain sites are located 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 periods and water 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 Summarise 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". Lag of marine proteins due to reductions in commercial fisheries will in a long-term perspective 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 due to various reasons, such as political, environmental, economic, 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 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 the variety of other stakeholders, commercial or recreational based. Table 4.2 gives an overview of the main reasons for the offshore development.

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 inshore 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 multifunctional use of sites of 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 cleaner water column
		constant temperature due to larger water body (less stress)
		higher mixing, availability and renewal of phytoplankton
		moving offshore could potentially reduce environmental impacts, reduce disease and improve candidate performance

		The potential to reduce some of the negative environmental impacts of coastal shellfish farming, and optimal environmental conditions for various marine species through the larger carrying and assimilative capacities
3	demand/ production	world demand for seafood increases annually by 2.2 million metric tons every year to maintain the current consumption of 29 kilograms per person each year (Worldbank, 2010) or by 40% 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 party solution
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 4.5.5)
		offshore systems can be constructed in a different design than installations nearshore (more space and therefore larger farm potential, deeper water allows submergible designs => less conflicts with shipping operations)
		potential to connect aquaculture installations with existing infrastructure (e.g. oil and gas platforms, offshore wind farms)
5	co-use with existing offshore installations	See in 4 above
		infrastructure for regular servicing may be shared (both industries require multi-use sources of transportation, preferably with lifting capacities to install and change plant components) - this provides an opportunity for both enterprises to share these high-priced facilities
		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 e.g. wind farm technicians to the offshore location at times of planned, preventive operation and maintenance activities)
		placement of mariculture devices in defined corridors between e.g. wind farm turbines reduces the special need through multiple use of ocean territories
6	Miscellaneous	seabed topography offshore (with an increasing distance from the shore) changes into deeper water which allows the submersion of equipment thus reducing the drag and load (due to wave action) on the entire system
		submergible systems allow the overstay during severe winter periods thereby saving money
		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 took 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 conferences called "Offshore Mariculture" were held in St. George's Bay (Malta) in 2006, in Alicante (Spain) in 2008 and in Dubrovnik (Croatia) in 2010. 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 further meetings and conferences are organised by e.g. the Institute for Marine Resources (IMARE) "Marine Resources and Beyond 2011" in Bremerhaven (Germany) in 2011. 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), by Michler-Cieluch (2009) and by Brenner (2009). For the Belgium Atlantic Coast Delbare (2001), MUMM (2005) and Van Nieuwenhove (2008) published reports on offshore aquaculture, for the Netherlands studies that explore the possibilities for mussel culture were written by Steenbergen *et al.*, (2005) and by Kamermans *et al.* (2011) and for the French coast a report was published too (Mille 2010). Finally, in Denmark a report was written by Christensen *et al.* (2009) concerning the potential for production of mussels in windfarms in the Baltic.

4.5.2 Experiences in ICES member countries

France: In France, commercial offshore mussel farming is taking place in 3 areas: in the Mediterranean Sea, at the Atlantic coast and in the North Sea.

In the Mediterranean offshore mussel farming is taking place in 4 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*) were done. The mussels are farmed on submerged longlines (Danioux *et al.*, 2000). In 1995 the production of offshore mussels dramatically decreased because of sea bream (*Sparus auratus*) predation. In 1995, 10000 tons of mussels were harvested, in 2004 - 4000 tons. In 2008, a licence was given for 1190 longlines with a length of 250m each. (Kamermans *et al.*, 2011).

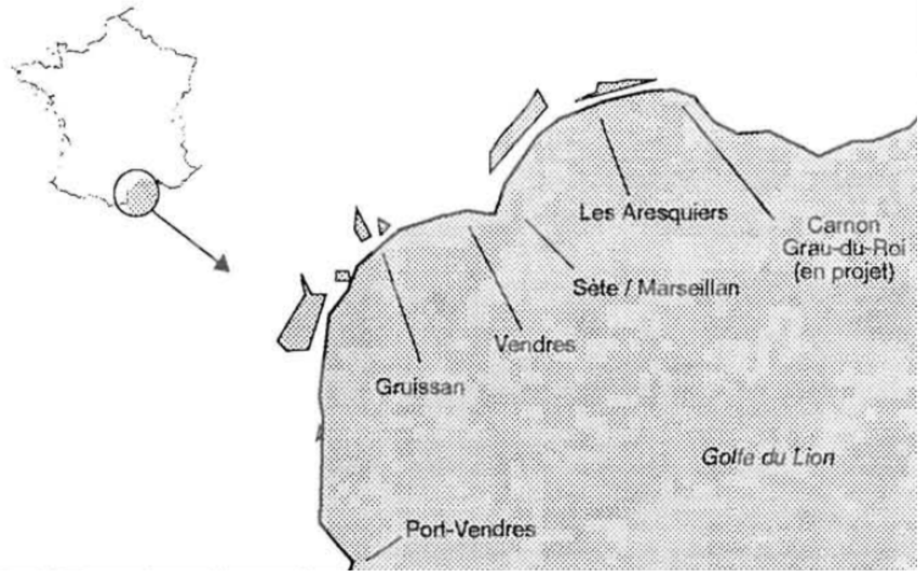


Figure 4.2. Location of the French offshore mussel cultures in the Mediterranean (source: Bompais, 1991).

At 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 (sometimes insufficient, for instance during cold and dry winters). Many ropes are used for production of "half-mussels", before transfer on intertidal bouchots (Kamermans *et al.*, 2011). The lines used called subfloating lines (Danioux *et al.*, 2000) are different from the Mediterranean longlines : they are nearer from 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 ones are still in operation (individual projects instead of 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 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).

Germany: 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. Further, other techniques such as suspended designs (e.g. longlines, longtubes) exist. Nevertheless, due to stakeholder conflicts (e.g. Buck et. al. 2004) and a lack of spat availability (Walter & Liebezeit 2003), mussel farmers tend to move offshore where it can be expected that space is not limited and adequate settlement guaranteed. Newcomers – the offshore wind farmers – are covering large areas in the German Bight which in contrast give the opportunity to use these areas in a multifunctional way by accepting mussel cultivation within the wind farms. All attempts to move mussel aquaculture off the coast to a more hostile environment are on pilot scale. Various projects including scientific studies on the biology, the techniques and the system design, the economic potential, ICZM and the regulatory framework as well as the potential synergy to offshore wind turbines were investigated (see Figure 4.3; for review see Buck *et al.* 2008).

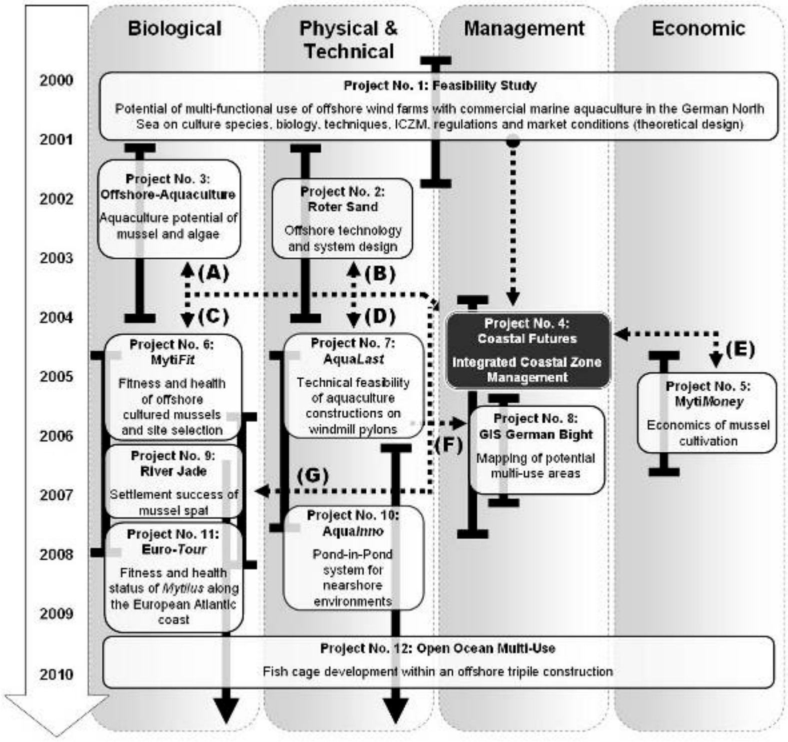


Figure 4.3. Chronological order of conducted and ongoing research projects dealing with the combination of offshore wind farming and open ocean aquaculture (modified after Buck *et al.* 2008).

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

Spain: In Spain there were no attempts yet to move shellfish operations off the coast into the open ocean.

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 chosen because they could not be used for other activities. The area D1 is situated near a shipwreck, the areas Oostdyck and Westhinder are located in the proximity of a measurement or radar pole and the area "op en 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 harbour of Nieuwpoort and, as it is the closest area to the coast, is preferred by the farmers. The main disadvantage of the area is the depth of only 8 meters, which makes the use of submerged longlines difficult. This forced the farmers to find alternative technologies such as buoys and cages. More recent the farmers started using submerged longlines in the area.

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

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

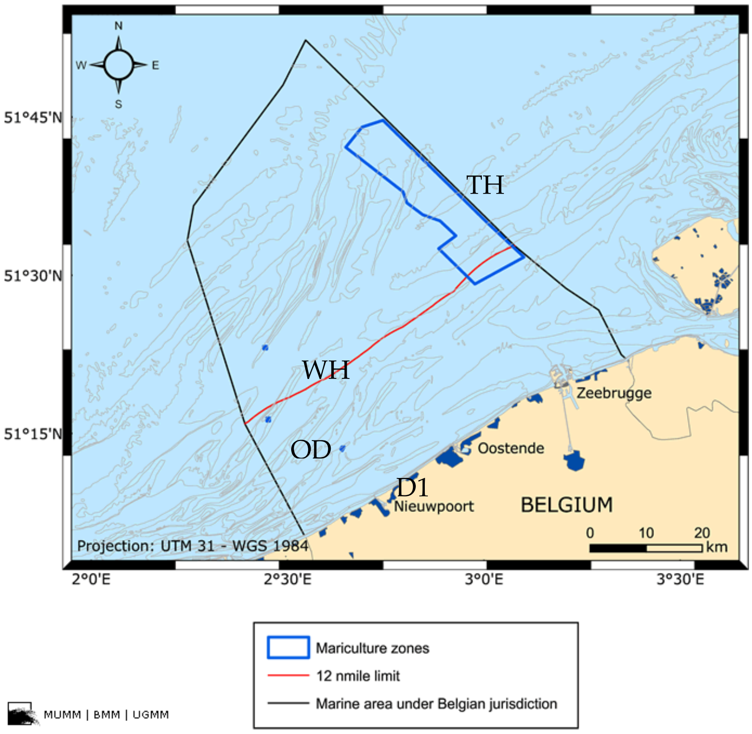


Figure 4.4. Location of the Belgian mussel areas D1, Oostdyck (OD), Westhinder (WH) and Thorntonbank (TH) (source: www.mumm.ac.be).

The Thorntonbank area is a large area that has a depth 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 it 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 and it will be completely forbidden by the new "Koninklijk Besluit" (Royal Decree) that is currently written. 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 fish farms. The fourth conference on Open Ocean Aquaculture was held in Canada too (see above). However, offshore shellfish farming in Canada is a new option. One mussel farm company just received funding for the development of a submersion system for offshore (exposed) mussel farms.

The Netherlands: 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 recent, 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).

Denmark: The Danish Government agreed on a development plan in 2006 and 2009 that supports a significant growth in mariculture. Increased production of fish will 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 bivalves. The Danish Aquaculture Association has identified offshore production as a solution in conflicts with an increased production and its correlation with the ongoing competitions for areas at sea. Furthermore, fish production can be beneficial in relation to discards of nutrients and CO_2 emissions by combining fish production with production of mussels and macroalgae (see Appendix A, Chapter 4).

Ireland: In Ireland, various test where 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.

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 an 15.4 km^2 offshore mussel farm. The farm, where the mussels will be grown on longlines, will be able to produce 10000 tonnes of mussels a year (Kamermans, 2011).

Information on other ICES countries (Norway, Sweden and Portugal) will be included in next year's report.

4.5.3 Candidates and Biological Research on OA

Several species can be farmed offshore in a hostile environment. Cheney *et al.* (2010) have listed bivalve species that can be farmed in offshore waters (Table 4.3). Most experiments and work to date have focused primarily on several mussel species and, to a lesser extent, on scallops and oysters. The reason why mussels are the preferred organisms to be cultured is because they are native species in most parts of the northern hemisphere which have a natural method of attachment with a "byssus" to objects in the water, furthermore they are hardy, readily seed themselves in the wild, are available year round (Seed & Suchanek 1992; Gosling 2003; Buck *et al.* 2010). Biological based investigations include growth performance, larval abundance, settlement, resistance to a harsh conditions, and the health and fitness of bivalve candidates.

Mussels cultivated in offshore areas mostly show high growth rates compared to nearshore sites (e.g. Buck 2004; Buck 2007b). This is due to the fact that water quality (e.g. urban sewage) and oxygen concentration are suitable and the infestation of parasites is low or nonexistent. Larval abundance decreases with increasing distance from shore (Walter *et al.* 2001), but is still sufficient at existing offshore farm sites (Buck 2007); absence of spat collection may also be viewed as an advantage (no fouling, only one year-class). The resulting settlement can lead to a one-step cultivation technique (no thinning procedure). The lower settlement success on one hand results – of course – 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 we recommend to collect the spat traditionally in nearshore areas and then transfer it to the offshore site (Christensen 2008). In Brittany (France), the local offshore spat contains hybrids of *M. edulis* and *M. galloprovincialis*. This hybrid mussels have the advantage of a better attachment, but have a lower commercial value (Bierne *et al.* 2002).

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 of the species (*M. galloprovincialis* more resistant than *M. edulis*) Mussels cultivated in a high energy environment will sooner or later adapt to this permanent physical stress. The growth performance of byssus threats changes in a stronger attachment as well as in the development of more threats.

In nearshore intertidal areas, mussels are potentially exposed to high concentrations of pollutants, pesticides, near surface agents and estuarine runoffs etc, which can pose a threat to consumer health. The scope of growth, i.e. the energy available for growth, is usually directly and positively correlated to a good overall health condition of the respective organism (Allen & Moore 2004). But organisms with high growth rates and a healthy appearance are no guarantee of a healthy food for human consumers. In waters eutrophicated by urban sewage, mussels show good growth performance. The microbial status of these mussels, however, excludes them most likely 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 infections. This should be less true for offshore cultivated mussels, where the environment is cleaner due to dilution of contaminants.

All known micro and macro parasites of the 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). Parasites living in blue mussels are numerous in some intertidal and nearshore areas. Buck *et al.* (2005) have shown that offshore grown mussels were free of macro-parasites. Infestation rates increased the closer the sites were to shore, where in particular intertidal mussels showed the highest numbers of parasites. In some Atlantic French sites however trematodes were found in (almost)offshore mussels. The debate over the effects of parasites on the energy status and overall health of the host is still open; data needed to elucidate these issues are still lacking.

Table 4.3. Locations and species cultured at selected offshore shellfish farm sites (Cheney *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*

Data source: Buck 2007a, b; Davis 2003; Jeffs 2003; Plew *et al.* 2005; Thompson 2006; Van Nieuwenhove and Delbare 2008.

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 this sector is worldwide in an early stage of development. Even if the production at individual farm sites is small by comparison with near shore farms, in the future offshore farms are proposed or under development which might, at full production, exceed the capacities of many nearshore farms (Cheney *et al.* 2010, Buck *et al.* 2010).

Traditional longline techniques cannot cope with the increased exposure to wave action, currents and wind as a result from moving offshore. 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 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, prevent the occurrence of sudden peak forces on the cables and prevent the excursion of the structure under sea state and current forcing (Bompais, 1991, Hampson *et al.* 2010).

In the seventies, CNEXO (France Institute) developed extensive researches on technology of longlines, including lot of trials in the field (Bompais, 1991). This resulted in commercial operations along the French Mediterranean coast and then Atlantic coast (Pertuis Breton). Cepralmar, in France, developed submerged longlines (Figure 4.5a), commercially used since the eighties along Mediterranean French coast, where the backbone rope is submerged to a depth were wave action has less impact on the system. A disadvantage of these systems is the depth needed: the backbone rope must be at least 5 meters below sea surface and therefore it cannot be used in shallow offshore areas (e.g. the Belgian offshore area D1 has a depth of 8 m only). Bompais (1991) and the Ifremer Technology team modified more recently (since 1985) the system for Atlantic coast, conceiving subfloating longlines (Figure 4.5b): in the subfloating longline, the floats are pencil-chaped to reduce the action of the waves on the longline (Bompais, 1991) (Figure 4.5). The submerged longlines developed by Langan & Horton (2003) are used in pilot projects over 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 8m and current velocities up to 1.5 m/s (Figure 4.7–4.8). In Iceland longlines were submerged down 10m under the sea surface in winter time.

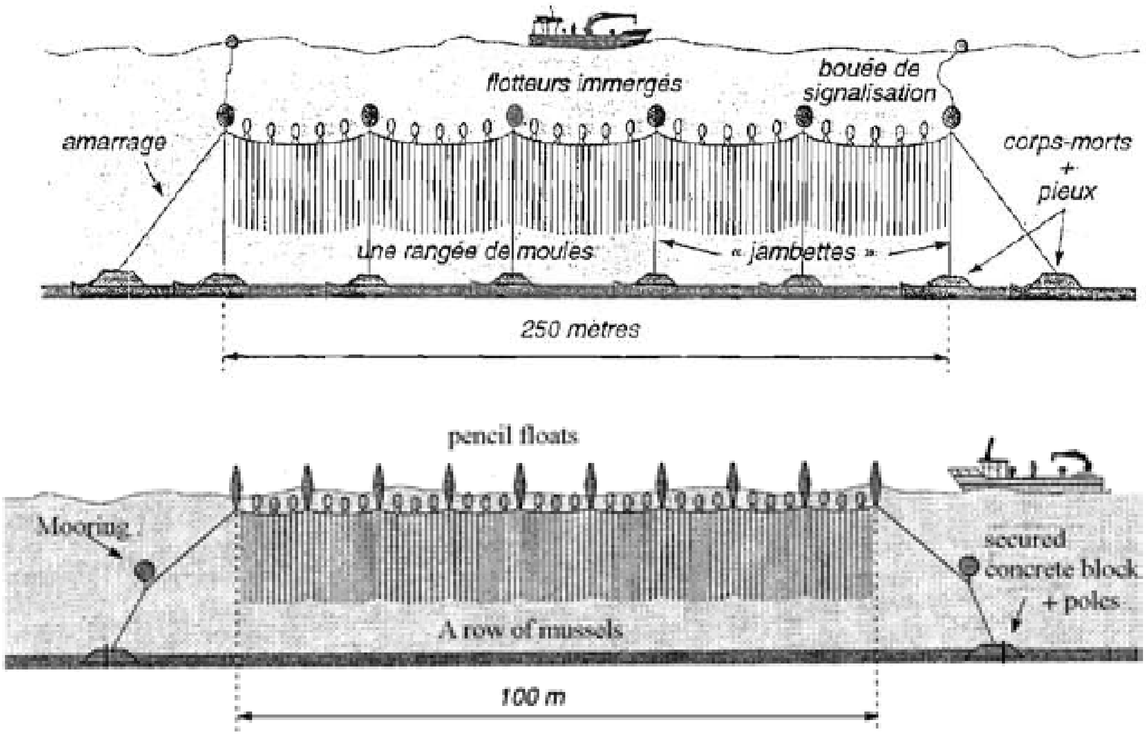


Figure 4.5. (a) Mediterranean subsurface (= submerged) longline and (b) Atlantic subfloating longline (source: Bompais, 1991 and Danioux *et al.*, 2000).

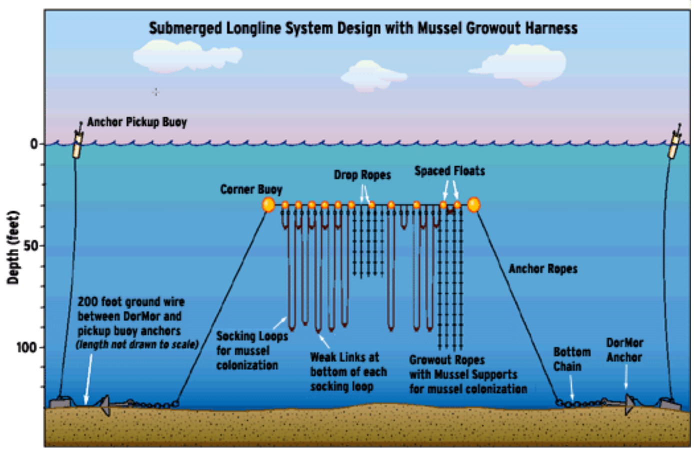


Figure 4.6. Subsurface longlines. No buoys attached to the backbone rope reach the surface to minimise wave impact. Source: Hampson *et al.* 2010.

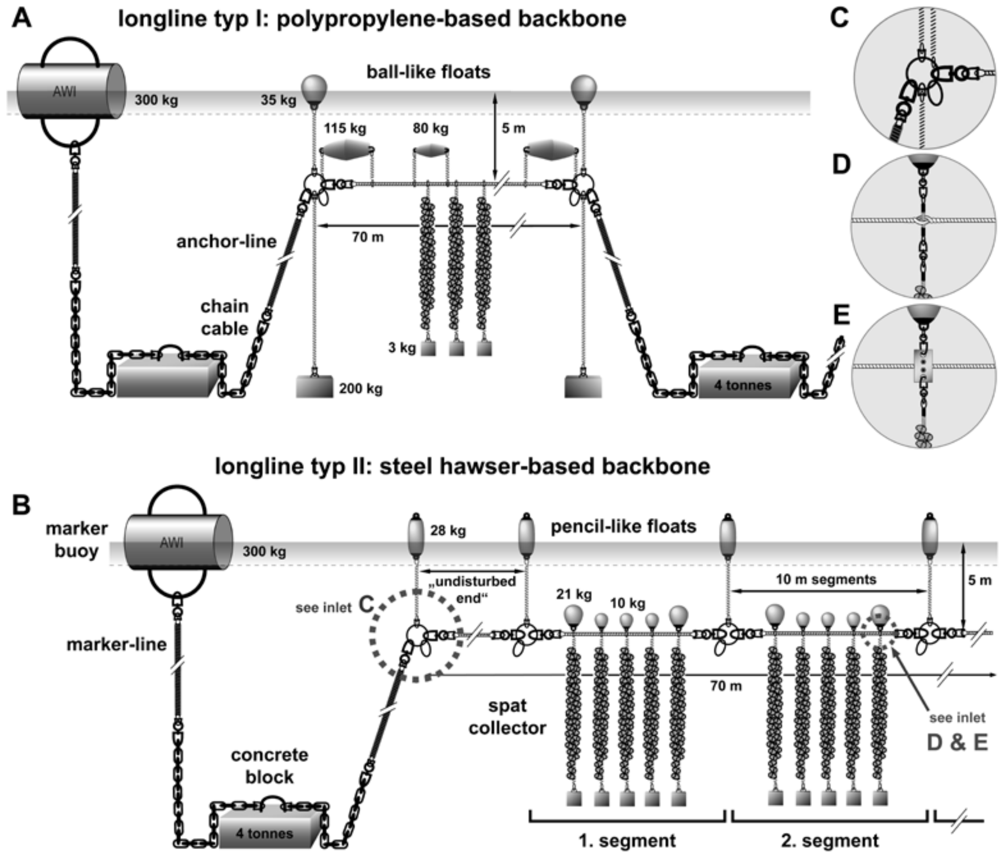


Figure 4.7. Submerged longline system designs with spat collector harness a polypropylene-based longline above (longline I) and b a steel hawser-based longline. The insets show the c coupling elements and d, e the connection of floats and collectors. c Polypropylene and steel hawser, d, e steel hawser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

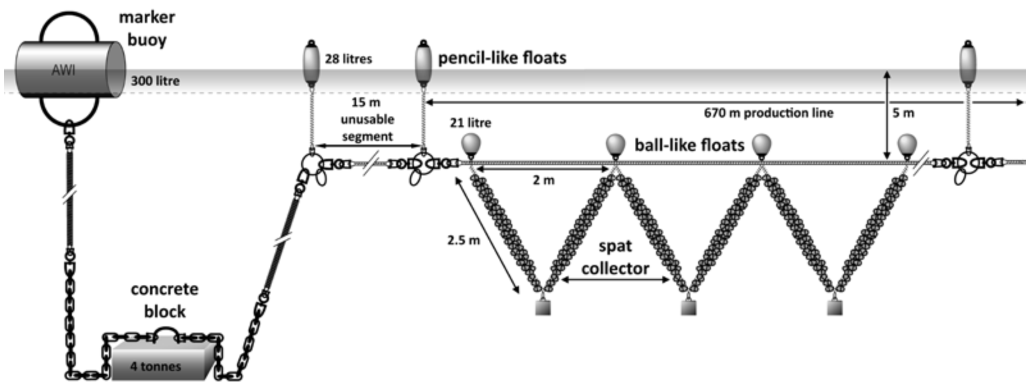


Figure 4.8. Example of a submerged longline system design with a V-shaped spat collector harness. In this image only a part of the 700 m long longline is presented (not to scale) (Buck *et al.* 2010).

As an alternative to the longline techniques various other constructions were developed and tested.

In Belgium a buoy for mussel farming was developed in 2006. The buoy, with a height and diameter of 5 meter contained 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 4.9). 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, etc 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 has its own mechanism, connected to the hydraulics of the ship, 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 by the North Sea (Figure 4.10).

Figure 4.9. A series of pictures of the harvest of the SDVO buoys (photographs: ILVO, Kris Van Nieuwenhove).

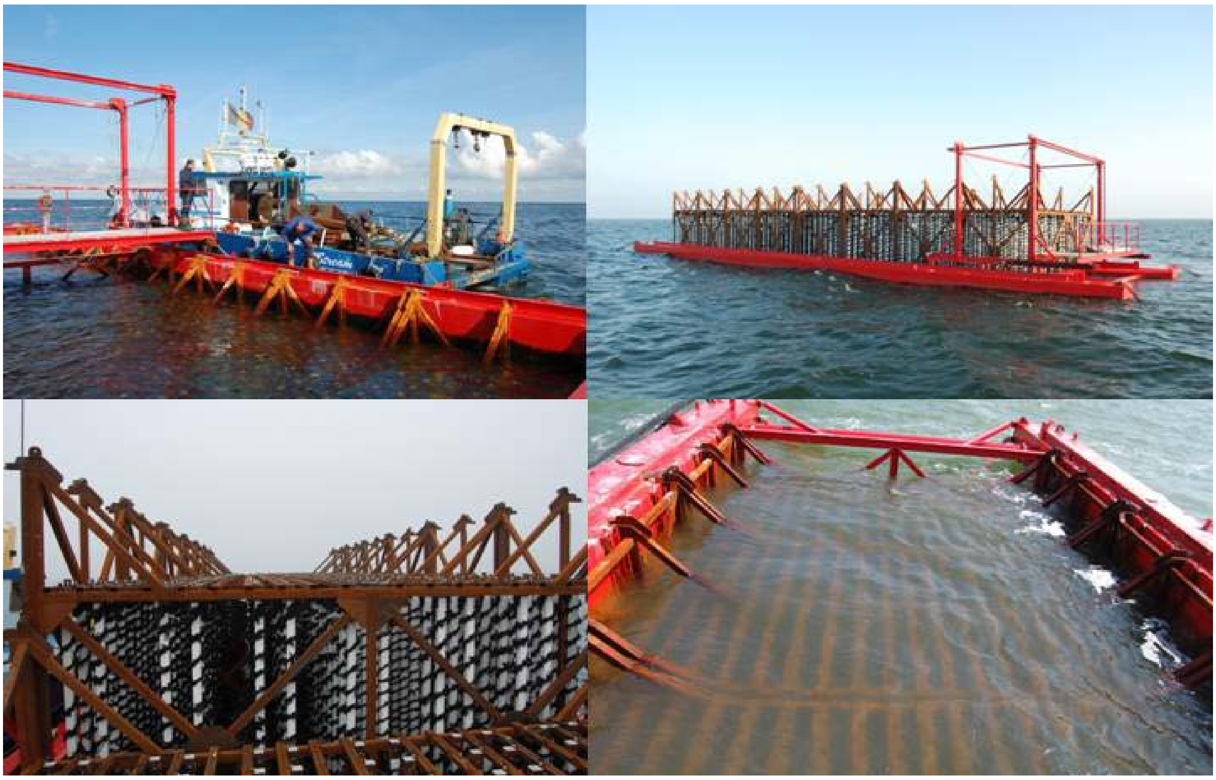


Figure 4.10. The Reynaert-Versluys pontoons (photographs: ILVO, Kris Van Nieuwenhove).

The "Mosseldobber" (the mussel float, Figure 4.11) was developed during the project "Mosselkweek in open zee" (mussel farming in open sea). The construction exists of a 5 meter long plastic tube whose top is filled with the floating polystyrol (styropoor) and whose bottom is filled with sand. Vertical ropes are attached on the outside. Originally they were made out of wood. In 2003 and 2004 the construction was tested in the Oosterschelde were 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).

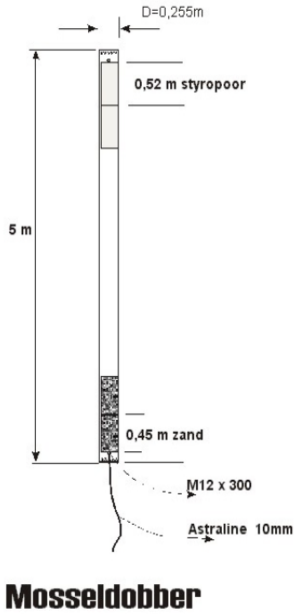


Figure 4.11. The mosseldobber (mussel float; Source: Den Boon).

Another construction was developed by Gafmar Seafood. The construction (figure 4.12) consists of a buoy connected to a ring. This first ring is linked to a second ring with a chain. Between both rings mussel rope is fixed. In normal conditions the constructions is positioned vertical in the water but for harvesting the construction can be lifted horizontal next to the working ship (Lont, Pers. Comm.)

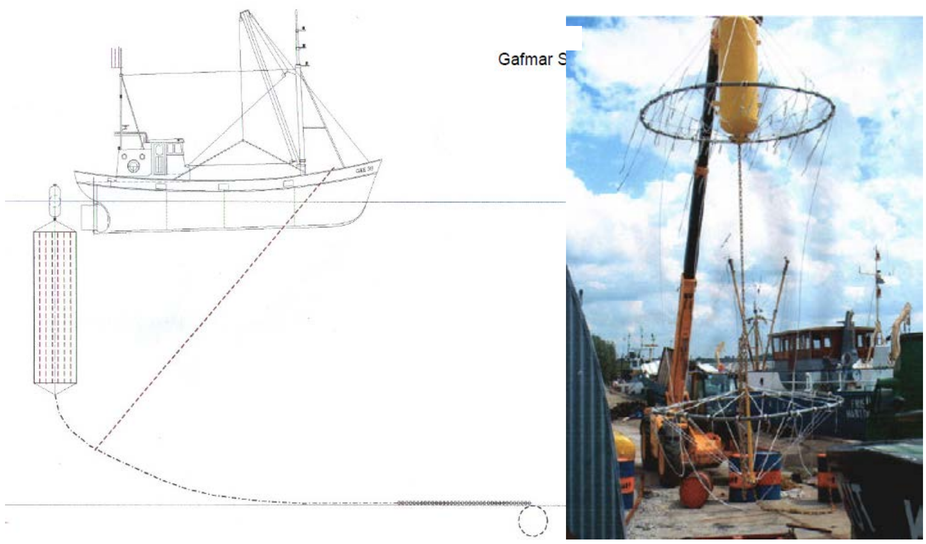


Figure 4.12. The Gafmar Seafood design (source: Den Boon).

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

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 are the placement of mariculture devices in defined corridors between wind farm turbines or the attachment to the foundations of windmills.

In Denmark desk-studies and field investigations have analyzed the potential for off shore production of blue mussels inside or outside windfarms. Research covers biological analyses of production potentials, analyses of how maintenance and operation and physical conditions set the limits for shellfish production. Furthermore, potential production methods are identified.

Aquaculture in a windfarm has at present to adapt to the conditions set by the windfarm operators (Stenberg *et al.* 2010). The operators may decide not to open the area or may decide to open at some specific conditions. Due to the high economic output of windfarms 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 windturbines and 2) maintenance due to breakdown. Maintenance can include use of smaller vessels that not interact with aquaculture activities, but also by huge platforms, that use most of the place between windturbines (480 to 800 m) anchoring and navigation. As a consequence no aquaculture or only activities with mobile units may take place between windturbines. Investigation of the physical conditions indicate that wind-and wave conditions may change significantly contrasting offshore locations in the Baltic to the North Sea (Stenberg *et al.* 2010, and that the windparks reduce wave activity heights by 2 to 10 % in the Baltic (Dong Energy and Vattenfalll 2006). Consequently, number of days an aquaculture can be operated varies as a function of location, season and technology at the production platform.

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 running on commercial scale are found in France and Belgium and a permit for an offshore mussel cultivation site was granted in 2010 to Offshore Shellfish Ltd, who would produce mussels off the coast of England. Other experiences exist of an offshore farm set up outside of Europe off the coast of New Hampshire (US). However, this farm is not in operation anymore. 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 compiles 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 favourable terms or actions could further improve profitability of offshore mussel cultivation. Altogether, the results are intended to shed some 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 off shore 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 off shore aquaculture evaluating how establishment, maintenance and production will be affected changing production structure from off shore 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 due 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 (e.g. 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 economical key numbers for mussel production in off shore 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.

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)	700×700 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 the last 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 establish an of shore farm and a mussel farm in a protected fjord indicate that the cost of the production unit is a factor 1.3 higher for off shore production when the cost is adjusted for production potential. The cost of a vessels is a factor 3.8 times higher for off shore production assuming the mussel farmer in the fjord only invest in a small vessel for maintenance, and rent 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 off shore 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, more numerous in these areas (French Mediterranean offshore culture of mussels almost completely depleted, since the nineties).

4.6 Site-Selection Criteria

Offshore aquaculture, like any other, should fulfil the requirements for carrying capacity compliance (physical, economical, ecological and social) and ensure the production of high quality products safe and healthy for consumption. Further, more generally, offshore aquaculture should fulfil the requirements for sustainable aquaculture (divided into 3 columns: ecological, economical, social). The following sections, which will be expanded at the next WGMASC meeting, may help to define site-selection criteria. Points of interest are the relation between offshore farming and fouling and harmful algal events.

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

"Bio-technical" opportunities and constraints derive from crossing between the requirements (or demand) for/of the cultivated species and husbandry gear/equipment on one hand, and the availability (offer) of environmental conditions of sites. Parameters to be considered are physical (exposure conditions, hydrodynamics), chemical (temperature, salinity…), and biological (food, toxic algae, predators and parasites…), and include:

- Special collector types to be used offshore (e.g. low drag design);
- No antifouling;
- Capacity of mussels conglomerates to adapt to strong currents. If available AND native, use strains which resist strong environments (*M. galloprovincialus* ⇔ *M. edulis*);
- Quantity, and quality of suspended particulate matter including the organic and inorganic sediment load;
- Physical oceanography controlling water temperature, salinity, the flux and mixing of suspended particulate matter (shellfish food, pathogens/parasites, particle reactive contaminants) and dissolved materials (oxygen and some contaminants);
- Cleaner environment (oxygen, urban sewage, lower tidal level, constant temperature, permanent mix, availability and renewal of phytoplankton);
- Abundance of predators (fish, birds…).

4.6.2 Consumption suitability

A detailed analysis of the overall health of the cultivated candidate together with data about e.g. parasite infestation, bacteria, virus and toxic algae concentrations can be used to characterise site conditions (Brenner *et al.* 2009). 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.

4.6.3 Ecological criteria

Possible interactions between aquaculture and wildlife preservation, particularly species at risk, and critical habitat have to be considered. In the case of OA, these interactions might be reduced in most cases. Protected diving birds may eventually interfere.

4.6.4 Economical criteria

Offshore culture systems will certainly cause higher investments costs. Therefore, site criteria of a culture plot should be well known to calculate economic risks. The specific conditions of OA have a direct impact on costs of production (investment in adapted boats and equipments, energy costs of transport…). The over-cost or reduced lifespan of the equipment for cultivation (e.g. longlines, buoys, …) or transportation (ships), or eventually the work conditions (harsh environment) or limited time at sea (due to harsh weather conditions) 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 & gas platforms), the over-cost should be reduced (e.g. Buck *et al.* 2010). The particular productivity of such sites may also enhance production levels. And then, a better quality of OA products (eventually recognized through labels or certifications) may yield better commercial prices (e.g. bio-products, differentiation).

4.6.5 Social and ICZM criteria

As with any site of the public domain, OA potential zones require collective agreement before allocation (with specific local rules of decision). For such sites, conflict uses should be reduced compared to onshore or nearshore aquaculture (less amenity and patrimony issues). Anyway, traditional former users like fishermen will probably be initially reluctant, even if some of them are part of the project. A solution could be a joint operation such as co-management.

4.7 Recommendations

- At present, several countries have initiated research to evaluate the potential for off shore 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 off shore 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 is identified included 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. Further work on this issue will be conducted by WGMASC in 2012.
- In the next decade an increasing high numbers of marine windparks will be established in off shore areas. The windparks may potentially support a production of bivalves. WGMASC should initiate an analysis of the potential for bivalve aquaculture in windparks. The analysis should focus on blue mussels, but also include other shellfish species.

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Appendix A: 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 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 report 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.

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

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 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, i.e. outwith farm areas constituting "natural populations" in many areas.

5.2.3 2009 report 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 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 Transfer of Marine Organisms (ICES 2003) are mentioned (see description field below). This text can be adapted to shellfish aquaculture issues also.

[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.

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.

5.2.5 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.

5.2.6 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.

5.2.7 2008 report of the WGEIM

Following ToR a) "Indices for the environmental effects of mariculture" which also deals with the development 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

Conclusions to be included in 2012

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 (C.ILY, 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 polychaets, such as *Polydora ciliata* inhabiting the shell of blue mussels, oysters, scallops and clams. This polychaet 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 sps,* 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. Metacercarias of trematods 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.

Independently of the final evaluation of the resulting health effects of different parasite species, a spreading of these species should be generally 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.

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.

Comparable to the diversity of species living as commensals on the shells of bivalves, numerous species are present in their intervalval water. 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 transfered 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.

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 health 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, 2000). 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.*, 1992), 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,m salinity and the present of organic debris and 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 fevers 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.

More 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 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 being 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 reversion 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 transfers of seed and the consequential 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. tros-*

sulus 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. 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 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, a clam species originated from Asia, was introduced into France in the 1980s for aquaculture purposes, including Arcachon Bay in 1980. For economic reasons, this aquaculture was unsuccessful and was rapidly abandoned, however, the species subsequently found good natural conditions to reproduce naturally 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 then contribute to the biodiversity modification in a 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 or carpet shells were introduced to England, carpeting areas of the foreshore, replacing the natural fauna there. Despite its impact no controls were sought – it established itself very quickly, destroying ecosystems. Under current EU health legislation, pests such as *Urosalpinx cinerea*, *Crepinula fornicata* and *Mytilicola* sps are not listed, being 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 modelling 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 spreading of the pathogen is much linked to hydrodynamics. It is becoming more and more possible to initiate field epidemiology, with some basic knowledge or hypothesis 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 more 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 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 informatics 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 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

- 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 thoughts about surrounding biological issues of transfers of shellfish from one area to another can be overlooked or ignored. Shortsightedness 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.

The WGMASC recommends that a review be conducted on all legislation pertaining to shellfish aquaculture (and fisheries) with a view to identifying areas or potential conflict and others where legislation is complementary.

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 of this Chapter.

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).

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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.

Please refer to the competent authority for guidance and advice on disinfection procedures.

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 molluscs (Gazeau *et al.* 2007). Consequently, climate changes will directly and indirectly influence numerous factors that are known to influence shellfish (University of Victoria 2000, Canadian Institute for Climate Studies 2000).

The WGAMSC focus is to consider the current scientific evidence for and effect of climate change on shellfish aquaculture in ICES countries and worldwide. To address this task, any available evidence on climate change impacts on cultured species needs to be accumulated and assessed. The ongoing 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 cultural practices or hazardous occurrence of a new virus strain? Evidence on 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 continued work on this topic will examine evidence that is consistent with a climate-change effect, but with an objective awareness of natural forcing factors.

6.2 Related ICES activities on Climate Change

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." In 2007, it was recommended that ICES create a cross-cutting multi-disciplinary steering group made up of members from a number of the existing committees to address issues of climate change that are brought to ICES from outside sources and to formulate appropriate responses to the issues. The ICES Steering Group on Climate Change (SGCC) 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 start-up transit of ICES toward the establishment of a programme in Climate Change. Following the implementation of the latest ICES Science Plan (2009–2013), the ICES SGCC was renamed as the Science Strategic Initiative on Climate Change (SSICC) in 2009. The SSICC will integrate 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; and
- 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 SSICC has encouraged ICES to establish a programme in Climate Change as the main instrument of ICES work in climate change and has recommended ICES adopt a formal resolution from ICES governing bodies to establish such a cross-cutting programme on climate change. This will ensure bottom up science, direct links with the groups and connections with ICES client demands. ICES expert group activities closely linked to addressing WGMASC tasks on Climate Change are summarized in the following sections.

6.2.1 Workshop on Climate related Benthos Processes in the North Sea (WKCBNS)

The ICES Benthos Ecology Working Group (BEWG) initiated a Workshop on Climate related Benthos Processes in the North Sea (WKCBNS; December 8 to 11, 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, as well for addressing shellfish aquaculture issues, was the prioritization of current climate change hypotheses as they relate to the benthos (see Annex 1). Information from this report

(ICES 2009a) has been instrumental in our ongoing efforts to review the available knowledge on climate change effects on shellfish culture.

6.2.2 Science Strategic Initiative on Climate Change (SSICC)

The Steering Group on Climate Change (SGCC) met for the first time in 2008 (ICES 2009b). The remit and responsibilities of the group are:

- Encouraging ICES member countries to provide relevant data for the study of climate change (e.g. historical data and data from long-term sampling sites);
- Identify appropriate methods of assessing information located in the ICES Data Centre and in non-searchable repositories;
- Identify functions and services that ICES can assume and provide in relation to climate change in the North Atlantic, provide added value to existing activities and so meet a demand of services and assessment presently not addressed;
- Advise ICES on the selection and preferred sequence of services that we can offer;
- Actively promote ICES services and assessment in climate change to potential users and stakeholders;
- Establish liaisons with international organizations, convention and panels with interest in the effects of climate changes in the oceans.

The group was renamed to the Science Strategic Initiative on Climate Change (SSICC). The SSICC is preparing a position paper on climate change and is recommending that a chapter on the socio-economic consequences of climate change in the North Atlantic be drafted during a workshop specifically tasked for this purpose. Inclusion of aquaculture-related perspectives has not been specifically identified, but should be considered within this workshop. The SSICC group recommends that their position paper on climate change (anticipated in 2010) should be seen as the official ICES view on climate change. This report will therefore serve as a critical reference point for planning future activities by the WGMASC within this term of reference.

In order to determine the capabilities of ICES expert groups in addressing the sixteen high priorities research topics, SCICOM has asked to identify their potential contribution to each of the high priority research topics.

6.2.3 Joint PICES/ICES Working Group on Forecasting Climate Change Impacts on Fish and Shellfish (WGFCCIFS)

A joint PICES and the ICES working group (WGFCCIFS) was formed to develop:

Annex 1: 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 shell-fish.

Annex 2: methodologies applied in designated case studies.

Annex3: techniques for estimating and communicating uncertainty in forecasts.

Annex 4: 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 main objective of the 2009 meeting was to agree to the structure of a science symposium organized under the auspices of the WG in April 2010 (Sendai, Japan).

In summary, WGFCCIFS is focused on the development of standardized quantitative frameworks for forecasting climate change impacts on commercially important fish and shellfish while the WGMASC is documenting available evidence of shellfish responses to climate shifts. Both group activities are linked to the WKCBNS focus on the identification of possible mechanisms underlying shellfish responses. It is therefore important to integrate these activities through enhanced communication/linkage between expert groups.

6.3 Background on Climate Change and Effects on Marine Benthic Species

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. Both activities must emphasize changes known to influence the production of high quality commercial shellfish products. Towards achieving the first objective, the following overview of climate change observations and scenarios is extracted, often verbatim, from an International Panel on Climate Change Synthesis Report (IPCC 2007), the ICES brochure "Climate Change: Changing Oceans", and 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).

"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). Global surface temperatures between 1995 and 2006 were among the twelve warmest years since 1850 and the temperature increase is greatest at higher northern latitudes. 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 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. Global average sea level rose 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. Between 1900 and 2005 precipitation has increased significantly in eastern parts of North America, northern Europe and northern and central Asia. It is 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.

Upper ocean temperature variability in the OSPAR Commission Maritime Area has been observed with high-quality measurements over the last 50–60 years (Figure 6.1; Hughes and Holliday, 2007). The *in situ* measurements demonstrate an interdecadal Atlantic Water temperature increase of about 1°C from the 1970s to the present, consistent along the shelf break from Ireland to the Barents Sea and the Fram Strait. In the North Sea, the rate of warming is even greater (1–2°C), whereas the warming in the western OSPAR regions is less (0.4–0.8°C; illustrated for the surface layer in Figure 6.1).

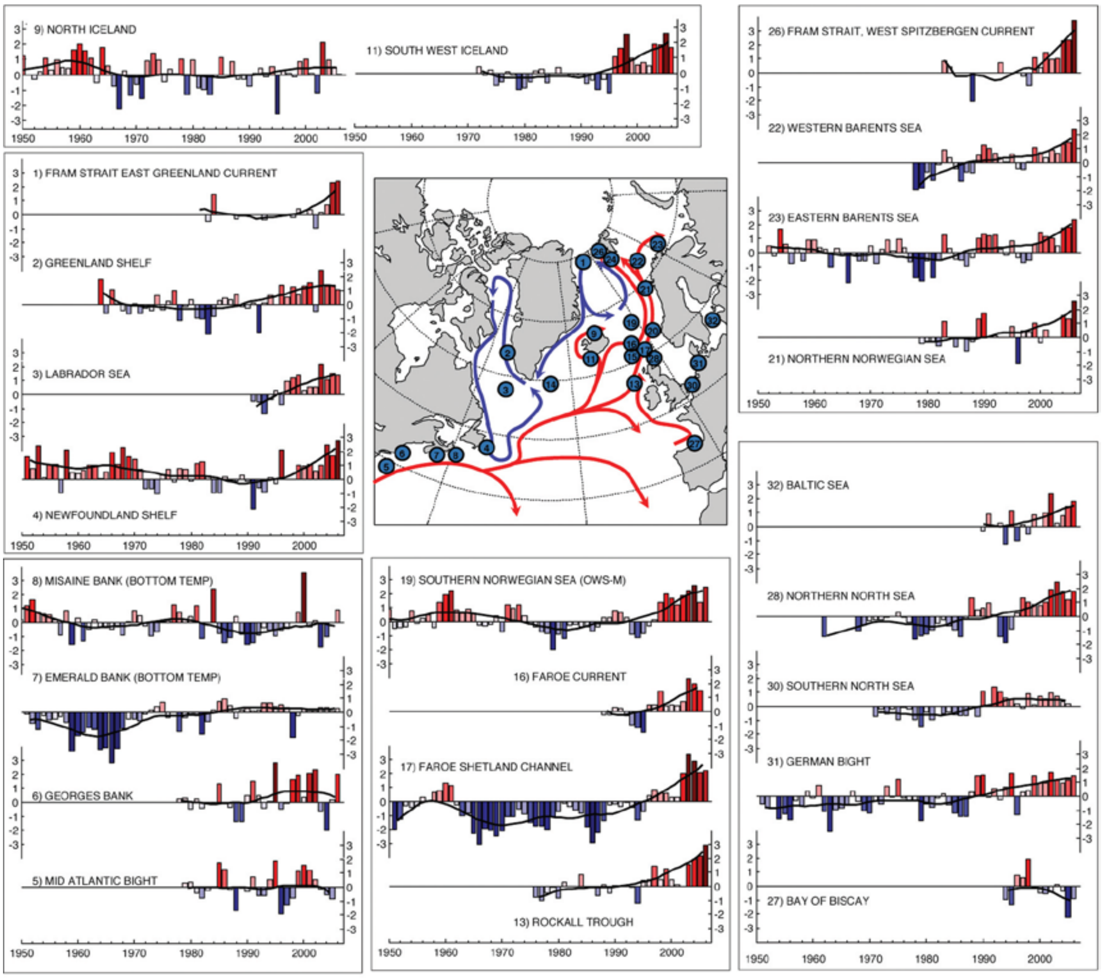

Figure 6.1. Overview of upper ocean temperature anomalies from the long-term mean across the North Atlantic. The anomalies are normalized with respect to the standard deviation (e.g. a value of +2 indicates 2 standard deviations above normal). The maps show conditions in 2006 (colour intervals 0.5; reds are positive/warm and blues are negative/cool). From Hughes and Holliday (2007) as published in Tasker *et al.* (2008).

Projections of future climate change in the near term, based on modelling of different scenarios, indicate an atmospheric warming of about 0.2°C per decade over the next two decades. Assuming continued greenhouse 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. The projected geographic patterns in warming trends and precipitation are expected to be similar to those observed over the past several decades. Larger peak wind speeds and more heavy precipitation will be associated with ongoing increases of sea-surface temperatures. Changes in precipitation lead to changes in runoff and seasonal runoff shifts. Runoff is projected with high confidence to increase by 10 to 40% by mid-century at higher latitudes. Anthropogenic warming and sea level rise would continue for centuries, even if GHG concentrations were to be stabilized, due to the time scales required for the removal of anthropogenic CO_2 emissions from the atmosphere.

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. The most vulnerable industries, settlements and societies are generally those in coastal and river flood plains, those whose economies are closely linked with climate-sensitive resources and those in areas prone to extreme weather events, especially were rapid urbanization is occurring. Coastal areas and industries are therefore projected to be exposed to high risks from climate change and sea level rise. 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 particularly stressed due to threat of sea level rise and increased risk from extreme weather events.

There is medium confidence that approximately 20 to 30% of all global species are likely to be at increased risk of extinction if increases in global average warming exceed 1.5 to 2.5°C (relative to 1980–1999). As global average temperature increase exceeds about 3.5°C, model projections suggest significant extinctions (40 to 70% of species assessed) around the globe. It is very likely that the meridional overturning circulation (MOC) of the Atlantic Ocean will slow down during the 21st century. Impacts of large-scale and persistent changes in the MOC are likely to include changes in marine ecosystem productivity, fisheries, ocean CO_2 uptake, and oceanic oxygen concentrations.

A meta–analysis of long-term datasets demonstrated that the changes in distribution, abundance, and other characteristics (particularly seasonality) of marine biota in this area are consistent with expected climate effects (Tasker *et al.* 2008). This includes 85 cases of changes in the 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. This analysis was confined to sea temperature effects from climate change and the authors cautioned that this does not mean that all changes are consistent with a climate-change effect, nor that climate is the only cause, but it is a recognizably important factor. Other key interlinked climate variables that can affect biota 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.

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). Such a shift can have a large impact on community functioning if biologically associated linkages are disrupted and populations' cycles are shifted out of phase with seasonal temperature cycles, food production and predator abundance. For example, 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). It is thought that warmer sea temperatures have already caused significant changes in phytoplankton and zooplankton populations, including changes in abundance and distribution. Changing weather patterns is also predicted to increase the formation of vertically stratified water. The duration of a stable seasonal stratification is predicted to increase as a result of climate change, because predicted higher rainfall will increase fresh-water inputs. Shellfish aquaculture is entirely dependent on the availability of natural trophic resources, including phytoplankton, which are dependent on nutrient supply to surface waters. In some regions, changes in plankton biomass and seasonal timing of blooms have been linked to the poor recruitment of some species whose life cycles are timed to make optimum use of these blooms.

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. These effects are compounded in situations where the benthic species that are affected create distinct habitats, for example, coral reefs or mussel beds." The creation of habitat by the introduction of cultured ecosystem engineers (e.g. mussels and oysters) will be similarly impacted. In addition, higher temperatures sustained the creation of oyster reefs in Europe.

The ICES workshop report on climate related benthos processes in the North Sea (WKCBNS; ICES 2009a) emphasized the need for enhanced research of climate influences on benthic communities owing to the complexity of benthic/pelagic coupling. Owing to the high intensity of some suspended and bottom bivalve culture activities, environmental interactions are highly complex, including numerous feedback mechanisms, and directed research is needed to understand and forecast additional changing climate influences.

Research carried out by ICES North Sea Benthos Surveys /project(?) (NSBP 2000). They did not consider specifically climate change and focused on other stresses on the North Sea – fishing, aggregate extraction and oil and gas exploration etc. However, the following main findings can be related to climate change:

- changes in the latitudinal distribution of some benthic species;
- changes in community composition; and
- the importance of large-scale hydrographic variables, such as bottom temperature, for the structuring of benthic (and fish) communities.

Some latitudinal shifts in distribution of benthic species, both northwards and southwards, have been documented and are related to the occurrence of warm and cool periods during the 20th century (reviewed by Tasker *et al.* 2008). These authors suggested that the strongest evidence of responses in benthic taxa that would be expected as a result of climate change is supplied in reports of :

- anomalously cold winter conditions leading to die-offs of species commonly associated with relatively warmer waters, or outbreaks of species commonly associated with relatively colder water; and
- benthic species expanding outside their historical ranges into more northerly or less coastal areas.

Such changes are likely to occur abruptly rather than incrementally over time owing to climate sensitivity in the benthos. An integration of large-scale benthos surveys (epifauna and infauna) into international survey programs was highly recommended (ICES 2009a) to study distribution shifts of benthic species and communities in response to climate driven changes of the ecosystem.

Additional information to be incorporated in this section in 2012

C.J.M. Philippart, R. Anadón, R. Danovaro, J.W. Dippner, K.F. Drinkwater, S.J. Hawkins,1, T. Oguz, G. O'Sullivan, P.C. Reid. 2011. Impacts of climate change on European marine ecosystems: Observations, expectations and indicators. Journal of Experimental Marine Biology and Ecology xxx (2011 in press).

"In general for the European Seas considered here the pattern of sea temperature over the last century has fluctuated from generally cold conditions in the early 1900s to a warm period from the 1920s to the 1950s, cool again through the 1960s and 1970s, followed by recent warming that commenced in the mid 1980s."

Table X. 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)

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 (Appendix C, Chapter 6). Table 6.1 summarizes these results and includes an additional column on the urgency of climate change issues from the perspective of its currently perceived influence on shellfish aquaculture. The following sub-sections report on the available evidence supporting some of these hypotheses.

Table 6.1. 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 based on expert judgement). 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 = more numerous invasive species	yes	negligible	high
Acidification effects	yes	negligible	high
Reduced mixing - deoxygenation	negligible	negligible	medium
Parasites infection rates - consequences for survival and reproduction	negligible	negligible	high
Reduced mixing - HABs effect on benthos food web (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 also considered effects on shellfish product quality in the coastal zone through contaminant bioaccumulation.**

6.4.1 Direct Effects of Temperature Change on Bivalve Culture

Water temperature is a key external factor mediating bivalve growth owing to the influence on a number of the physiological components of growth (ingestion and maintenance specially). However, it is often difficult to assign causality for growth changes to temperature variations owing to the complex interplay that exists between a wide array of exogenous and endogenous forcing factors that control growth. Ferreira *et al.* (2008) developed a modelling framework that enables 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 at Strangford Lough (Northern Ireland) and predicted a reduction in shellfish culture productivity and a decrease in both the mean weight and mean length of individuals. An increase of 1°C in the average 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) 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 (Figure 6.2). 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 time-scale of climate change.

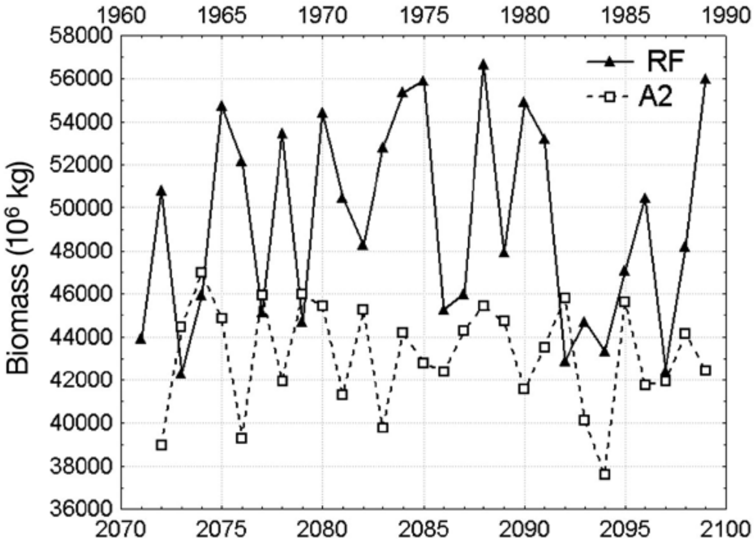

Figure 6.2. Model predictions of the time course of the annual total clam biomass production in the reference (RF; 1961–1990) and future A2 (2071–2100) scenarios (Malaku-Canu *et al.* 2010).

6.4.2 Geographic Shifts in Shellfish Species Distribution

As noted by Tasker *et al.* (2008), the strongest evidence of responses of benthic species (including cultured bivalve molluscs) 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. This can result from the lack of die-offs 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.

An examination of the temperature tolerance of different bivalve molluscs may serve as a first-order approximation of the susceptibility of aquaculture species to global warming trends. However, this approach is confounded by other factors that make it difficult to predict species responses to regional temperature variations. 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 a temperate waters, owing to the wider thermal tolerance of the later (Compton *et al.*, 2007). The detection of a link between climate change and species distribution will more likely come from observed biogeographical changes.

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), Diederich *et al.* (2004) 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. Reviewing expected effects of climate change on distribution of *Crassostrea gigas*, Troost (2010) inferred that warm summers are the main determinant for recruitment success that promote extensive spatfalls near its northern distribution limit. It was concluded that the further invasion of *C. gigas* in the northern Wadden Sea would depend on high 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 increased rates of population increase of the Pacific oyster while the abundance is expected to decline due to increased predation rates in the subtidal and lower intertidal as a consequence of mild winters. 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 is westward, and continues northward along the Norwegian western coast (Sætre *et al.* 1988). The current pattern and time-scales of weeks to months of the 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).

In Ireland, Pacific oyster culture has been conducted since 1974. The conventional wisdom at the time of its introduction was that water temperatures were such that the species could not successfully reproduce (same for *Tapes philippinarum* in France). 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). Localized 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 (Figure 6.3). It is anticipated that this temperature increase allied with increase standing stock (spawning biomass) has facilitated successful recruitment at this site.

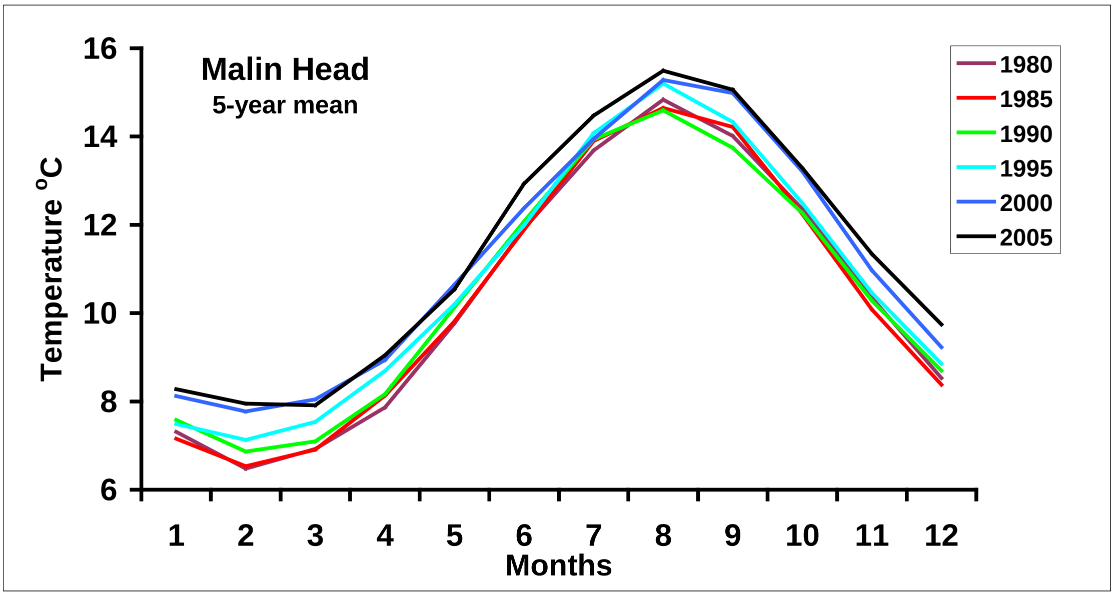

Figure 6.3. Five-year-means of water temperature recorded form Malin Head, Ireland from 1980–2005 (Source: Met Eireann).

The native European flat oyster (*Ostrea edulis*) has its northern distribution on the Norwegian south-western coast, where it historically has been 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). However, the new situation can also provide opportunities for new cultures.

Berge *et al.* (2005, 2006) examined inter-annual variations in ocean temperatures and the increased northward volume transport of Atlantic water and suggested that a recently discovered population of *Mytilus 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 population dynamics of cold-water bivalve species are strongly related to temperature and mild winters in northwestern European estuaries have resulted in low bivalve recruit densities and small adult stocks (cockle *Cerastoderma edule,* Baltic tellin *Macoma balthica,* gaper clam *Mya arenaria* and the blue mussel *Mytilus edulis*; reviewed by Philippart *et al.* 2003). These authors suggest that the current rapid rate of temperature increase could lead to long periods of poor recruitment of wild bivalve stocks and an increase in warm-water species in northwestern European estuaries.

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 *et 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 *et 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 (*Cerastoderma edule*, *Mya arenaria*, and *Macoma 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.

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). However, it must be considered that temperature amplitude between south and north range of a species like *C.gigas* exceeds the foreseen warming. On the other hand, effects are complex and sometimes unexpected: for instance, the best survival of oyster spat in France was observed in very high air exposure time (50%), due to low growth and reproduction of oysters or less virus prevalence (Pers. comm. J. Mazurie). 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.

6.4.3 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-}):

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

This results 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). This change in pH 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 molluscs require the availability of sufficient amounts of CO_3^{2-} for shell formation and excessive ocean acidification will 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.

These authors 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 largely unknown and should be included in future studies in terms of: (1) calcification response, (2) organism response, (3) ecosystem response, and (4) socio-economic response.

To date, studies of the effects of elevated pCO_2 on marine calcifiers have been confined to just a few species (Kleypas *et al.* 2006), and there remain large gaps in knowledge of the physiological and ecological impacts of increasing pCO_2 on these organisms. Gazeau *et al.* (2007) realized the first study to pCO_2 levels within the range of values projected by the IPCC (up to 1250 ppmv in 2100). They showed that the calcification rates of important aquaculture species (*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 ~1,800 ppm. It was projected that mussel and oyster calcification may decrease by 25 and 10%, respectively, by the end of the century. Longer-term exposures of *Mytilus galloprovincialis* at pH = 7.3 (consistent with a pCO_2 of about 1900 μatm) also induced significant growth reduction and shell dissolution owing to reduced haemolymph bicarbonate levels (Michaelidis *et al.* 2005). However, Berge *et al.* (2006) showed that the growth of *M. edulis* at pH levels of 7.4 and 7.6 was not significantly different from growth at normal pH 8.1. This apparently contradictory result may be explained by adaptation by the mussels during a 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). Bibby *et al.* (2008) investigated the immune response in mussels (*Mytilus edulis*) exposed to acidified (using CO_2) sea water, and suggested that ocean acidification may impact the physiological condition and functionality of the haemocytes. Calcium carbonate shell dissolution could have a significant effect on cellular signalling pathways, and particularly those pathways that rely on specific concentrations of calcium.

Larval and juvenile bivalves are particularly sensitive to ocean acidification and high mortality rates have been linked to calcium carbonate dissolution (Green *et al.* 2004, Fabry *et al.* 2008). This and the other studies reported above give 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.

Studies on other marine calcifiers have provided some general conclusions on responses to acidification (based on review by Kleypas *et al.* 2006):

- Benthic calcifiers have shown a significant calcification response from carbonate chemistry. For example, the average response of corals is a 30% decline in calcification in response to a doubling in CO_2.
- Exposure to elevated CO_2 can affect physiology as well as calcification rate in many benthic organisms.
- The interactive effects of saturation state, temperature, light, and nutrients, are important factors in calcification rates of reef organisms.
- Identification of cause-effect relationships is difficult because calcification rates in the field are a response to multiple variables (light, temperature, nutrients, etc.) and particularly to rising temperature.

- Several years may be necessary to determine whether benthic calcifiers can adapt or acclimate to different carbonate chemistry conditions.

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. 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). 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 fishery revenues from shellfish and their predators.

Additional papers: results will be summarized in the text above in 2012

Salisbury, J., M. Green, C. Hunt, and J. Campbell (2008), Coastal acidification by rivers: A new threat to shellfish? Eos Trans. AGU, 89(50), 513.

O'Donnell, M. J., M.H. LaTisha, G.E. Hofmann. 2009. Predicted impact of ocean acidification on a marine invertebrate: elevated CO_2 alters response to thermal stress in sea urchin larvae. Mar Biol (2009) 156:439–446. Sea urchins.

- Alterations in seawater chemistry may manifest themselves directly in the calcification process, or have synergistic effects with other environmental factors such as elevated temperatures. Paper highlights the importance of looking at multiple environmental factors simultaneously as this approach may reveal previously unsuspected biological impacts of atmospheric changes. It is important to understand the interaction between OA and other environmental stresses.
- A significant gap in our knowledge regarding the biological impacts of OA is the degree to which life in a high CO2 world has costs and effects on physiological processes besides calcification (see e.g., Fabry *et al.* 2008; Widdicombe and Spicer 2008).
- A significant research gap is the need to understand the limits to organisms' ability to successfully respond to future environmental conditions, especially multiple, interacting stressors.
- An especially fruitful area for this research is to focus on early life history stages whose rapid growth may show differences in response to the environment more quickly than adults. Since early life history stages are difficult to study in the field, OA effects on larvae may have large impacts on adult populations, but are difficult to identify through traditional population studies. Hence, understanding the mechanisms by which OA may act on larval stages is critical to making predictions about broader ecological impacts.
- Ocean environments present developing larvae with a variety of potentially stressful conditions, and organisms' responses to OA need to be considered in the context of multiple stressors. These will act on different

physiological systems and at different time scales, eliciting a variety of responses. In general, the time scale of OA is long relative to the development of individuals (i.e., the oceans will not become more acidic over the weeks to months that marine larvae develop in the plankton), although some processes such as upwelling can alter ocean pH over much shorter time scales (e.g., Feely *et al.* 2008).

- Used expression of a central molecular chaperone, hsp70, as a bioindicator to assess changes in the response to temperature.

Parker, L.M., P.M. Ross and WA O'Connor. 2009. The effect of ocean acidification and temperature on the fertilization and embryonic development of the Sydney rock oyster Saccostrea glomerata (Gould 1850). Global Change Biology 15: 2123-2136

- Abstract: This study 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 (Gould 1850). As pCO_2 increased, fertilization significantly decreased. The temperature of 26°C was the optimum temperature for fertilization, as temperature increased and decreased from this optimum, fertilization decreased. There was also an effect of pCO_2 and temperature on embryonic development. Generally as pCO_2 increased, the percentage and size of D-veligers decreased and the percentage of D-veligers that were abnormal increased. The optimum temperature was 26°C and embryonic development decreased at temperatures that were above and below this temperature. Abnormality of D-veligers was greatest at 1000 ppm and 18 and 30°C (≥90%) and least at 375 ppm and 26°C (≤4%). Finally prolonged exposure of elevated pCO_2 and temperature across early developmental stages led to fewer D-veligers, more abnormality and smaller sizes in elevated CO_2 environments and may lead to lethal effects at suboptimal temperatures. Embryos that were exposed to the pCO_2 and temperature treatments for fertilization and embryonic development had fewer D-veligers, greater percentage of abnormality and reduced size than embryos that were exposed to the treatments for embryonic development only. Further at the elevated temperature of 30°C and 750–1000 ppm, there was no embryonic development. The results of this study suggest that predicted changes in ocean acidification and temperature over the next century may have severe implications for the distribution and abundance of *S. glomerata* as well as possible implications for the reproduction and development of other marine invertebrates.

F. Gazeau1, J.-P. Gattuso1, C. Dawber, A. E. Pronker, F. Peene, J. Peene, C. H. R. Heip, and J. J. Middelburg. 2010. Effect of ocean acidification on the earlylife stages of the blue mussel (Mytilus edulis). Biogeosciences Discuss., 7, 2927–2947.

- Abstract: This study 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* (Gould 1850). As pCO_2 increased, fertilization significantly decreased. The temperature of 26°C was the optimum temperature for fertilization, as temperature increased and decreased from this optimum, fertilization decreased. There was also an effect of pCO_2 and temperature on embryonic development. Generally as pCO_2 increased, the percentage and size of D-veligers decreased and the percentage of D-veligers that were abnormal increased. The optimum temperature was 26°C and embryonic development decreased at temperatures that were above and below this temperature. Abnormality of D-veligers was greatest at 1000 ppm and 18 and 30 °C (≥90%) and least at 375 ppm and 26°C (≤4%). Finally prolonged exposure of elevated pCO_2 and temperature across early developmental stages led to fewer D-veligers, more abnormality and smaller sizes in elevated CO_2 environments and may lead to lethal effects at suboptimal temperatures. Embryos that were exposed to the pCO_2 and temperature treatments for fertilization and embryonic development had fewer D-veligers, greater percentage of abnormality and reduced size than embryos that were exposed to the treatments for embryonic development only. Further at the elevated temperature of 30°C and 750–1000 ppm, there was no embryonic development. The results of this study suggest that predicted changes in ocean acidification and temperature over the next century may have severe implications for the distribution and abundance of *S. glomerata* as well as possible implications for the reproduction and development of other marine invertebrates.

Stephanie C. Talmage and Christopher J. Gobler. 2010. Effects of past, present, and future ocean carbon dioxide concentrations on the growth and survival of larval shellfish. Proc. Nat. Academy Sci. 107:17246–17251.

- Abstract: The combustion of fossil fuels has enriched levels of CO2 in the world's oceans and decreased ocean pH. Although the continuation of these processes may alter the growth, survival, and diversity of marine organisms that synthesize CaCO3 shells, the effects of ocean acidification since the dawn of the industrial revolution are not clear. Here we present experiments that examined the effects of the ocean's past, present, and future (21st and 22nd centuries) CO2 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 preindustrial CO2 concentrations (250 ppm) displayed significantly faster growth andmetamorphosis aswell as higher survival and lipid accumulation rates compared with individuals reared under modern day CO2 levels. Bivalves grown under near preindustrial CO2 levels displayed thicker, more robust shells than individuals grown at present CO2 concentrations, whereas bivalves exposed to CO2 levels expected later this century had shells that were malformed and eroded. These results suggest that the ocean acidification that has occurred during the past two centuries may be inhibiting the development and survival of larval shellfish and contributing to global declines of some bivalve populations.

Richard A. Feely, Simone R. Alin, Jan Newton, Christopher L. Sabine, Mark Warner, Allan Devol, Christopher Krembs, Carol Maloy. 2010. The combined effects of ocean acidification, mixing, and respiration on pH and carbonate saturation in an urbanized estuary. Estuarine, Coastal and Shelf Science 88: 442-449.

- Abstract: Puget Sound is a large estuary complex in the U.S. Pacific Northwest that is home to a diverse and economically important ecosystem threatened by anthropogenic impacts associated with climate change, urbanization, and ocean acidification. While ocean acidification has been studied in oceanic waters, little is known regarding its status in estuaries.

Anthropogenically acidified coastal waters upwelling along the western North American continental margin can enter Puget Sound through the Strait of Juan de Fuca. In order to study the combined effects of ocean acidification and other natural and anthropogenic processes on Puget Sound waters, we made the first inorganic carbon measurements in this estuary on two survey cruises in February and August of 2008. Observed pH and aragonite saturation state values in surface and subsurface waters were substantially lower in parts of Puget Sound than would be expected from anthropogenic carbon dioxide (CO2) uptake alone. We estimate that ocean acidification can account for 24–49% of the pH decrease in the deep waters of the Hood Canal sub-basin of Puget Sound relative to estimated pre-industrial values. The remaining change in pH between when seawater enters the sound and when it reaches this deep basin results from remineralization of organic matter due to natural or anthropogenically stimulated respiration processes within Puget Sound. Over time, however, the relative impact of ocean acidification could increase significantly, accounting for 49–82% of the pH decrease in subsurface waters for a doubling of atmospheric CO2. These changes may have profound impacts on the Puget Sound ecosystem over the next several decades. These estimates suggest that the role ocean acidification will play in estuaries may be different from the open ocean.

Gisela Lannig,Silke Eilers, Hans O. Pörtner, Inna M. Sokolova, and Christian Bock. 2010. Impact of Ocean Acidification on Energy Metabolism of Oyster, Crassostrea gigas—Changes in Metabolic Pathways and Thermal Response. Mar Drugs. 2010; 8(8): 2318–2339.

- Abstract: Our present study demonstrates that CO_2 levels corresponding to expected OA scenarios are likely to interfere with the energy metabolism of oysters. This may reflect vulnerability to OA and temperature extremes. These findings are especially noteworthy because oysters, like other estuarine invertebrates, are normally exposed to broad fluctuations in CO_2 levels, pH and temperature in their habitats and thus should be better adapted to these changes than their deep-water or open-ocean counterparts. Nevertheless, chronic hypercapnia affects energy metabolism even in this eurybiont species especially when combined with elevated temperature. Synergistic effects of elevated temperature and hypercapnia were also identified in other bivalves and are consistent with earlier reports that elevated temperature enhanced the sensitivity to a variety of environmental stressors such as pollution, hypercapnia or oxygen deficiency. However, species-specific physiological differences in biomineralization as well as energy metabolism and acid-base regulation may shape differential sensitivities of various marine invertebrates to OA and elevated temperature thus complicating the picture of ecosystem-level responses of marine organisms to a high CO_2 world. Further studies are critically needed to determine the range of sensitivities of key marine species to OA and global climate change and the mechanisms setting limits to their tolerance to elevated temperatures and low pH in the future oceans. Analyses of energy metabolism as in the present study can provide a useful integrative view of stress effects on physiological performance of a variety of marine species and characterize their tolerance and tolerance limits in the face of global change.

6.4.4 Anecdotal information on climate change Effects on Shellfish aquaculture

Expand in 2012. Greater involvement of industry - monitoring of crops

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

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. The aim of the WFD is to obtain a "good status" of water bodies. However, this iterative management system with 6 year cycles of monitoring, assessments, and planning is 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. 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 consequences of climate change.

6.6 Recommendations

1) ICES activities related to climate change issues are inherently linked and the WGMASC supports the SSICC recommendation for ICES to adopt a formal resolution from ICES governing bodies to establish such a cross-cutting programme on climate change. In the interim, the WGMASC will continue to review outputs from other relevant expert groups and to integrate these results into our activities. An integrated approach to addressing aquaculture aspects of climate change may be for the WGEIM to expand upon the current work of the WGMASC. Key members of the WGEIM are also invited to actively participate in WGMASC meetings where this ToR is addressed (SCICOM, WGEIM, WGFCCIFS, SGICC).

2) The research effort on the effect of climate change on cultured shellfish species is largely in its infancy, but is increasing rapidly. Rather than continue to simply review project results as they become available, we recommend that the WGMASC focus future activities on the provision of advice on related research and management priorities. However, it will be important to continue to keep abreast of research relating to the effects of climate change on shellfish aquaculture (SCICOM).

6.7 References

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Appendix C: List of climate change hypotheses

The following list of hypotheses related to climate change and the conceptual model illustrating climate effects on benthos is based on Annex 3 of the ICES WKCBNS REPORT (ICES, 2009).

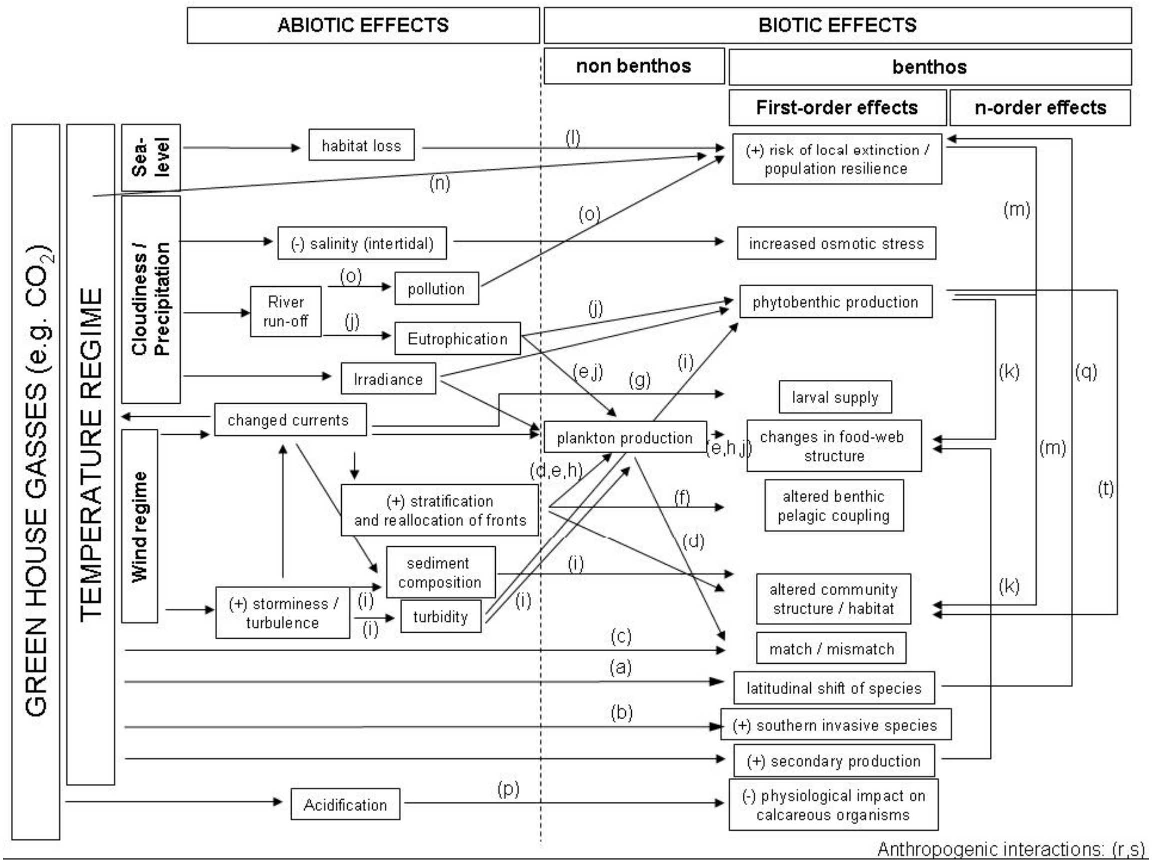

Figure C.1. Conceptual model of the links between climate change and benthic communities (hypotheses indicated by the letter below).

(*a*) Poleward shifts in the latitudinal distributions of species, with consequent changes in species composition and species richness at any given location.

(*b*) Rising temperature could enable more human introduced species to invade and become established, replacing current native species.

(*c*) Climate change might result in changes in the timing of reproduction. This might result in a temporal mismatch between the larval period and/or settlement and the availability of food, i.e. the plankton bloom.

(d) Stratification and spring blooms of plankton in our shelf seas will occur earlier in a warmer climate. This might result in a temporal mismatch as mentioned above.

(e) Reduced mixing of the water column (increased stratification) may favour many Harmful Algae Blooms-causing species. This might have effects on the benthos food web relying on phytoplankton as primary food source.

(f) Reduced mixing may also enhance the risk of oxygen depletion and result in al-tered pelagic-benthic coupling.

(g) Changing wind directions may lead to changing local surface currents resulting in changes in larval transport and, thus, species distribution.

(h) Altered current conditions may lead to shifts in frontal areas and may change upwelling situation. This will influence primary production with consequences for the food supply to the benthos.

(i) Changes in the frequency and intensity of storms will change the wave energy which will have an impact on the benthic environment.

(j) Changes in nutrient fluxes due to advection, vertical diffusion and mixing, river flows and atmospheric deposition, leading to changes in primary production with consequences for the secondary production and biomass of the benthos.

(k) Changes in the production and biomass of benthic species will have implications for the food web dynamics.

(l) Sea-level rise may accelerate the loss of intertidal habitats also because of increased coastal defences (e.g. hard structures, islands, beach nourishment).

(m) Community changes including habitat forming species will result in altered habi-tats.

(n) Changes in the temperature regime might lead to extreme high temperatures in the intertidal, including runnels on beaches, leading to decreased survival of some species (e.g. juvenile shrimp).

(o) Climate change may influence terrestrial inputs of pollutants and the release of pollutants currently locked in seabed sediments with consequences for the benthos such as effects on reproduction and local extinctions.

(p) Future increases in ocean acidity will have major negative impacts on some shell/skeleton-forming organisms.

(q) An increased distribution of parasites (such as trematodes) will lead to higher in-fection rates of benthic species with consequences on survival and reproduction.

(r) Anthropogenic impacts caused by drivers such as fisheries and pollution may de-crease the resilience of the benthic community and/or of certain benthic species to changing climatic conditions, further endangering their populations (slightly altered to include community and species level effects).

(s) Synergistic and antagonistic effects of climatic and anthropogenic effects. (This hypothesis has been reformulated as the original formulation was ambiguous: "Changes of anthropogenic actions (e.g. fisheries, sand extraction) will have conse-quences for the benthic environment").

(t) Climatic induced changes in phytobenthic plant species composition and coverage will influence the associated faunal composition as well as animals seeking repro-duc-tion, nursery areas as well as food within the phytobenthic zone.

(u) Alternative production (e.g. the increase of opportunists) will increase the export of organic matter to the benthos of deeper waters, providing food, but also cause an-oxia in the deeper waters.

7 Report to SSGHIE on potential and current contributions of WGMASC to the Strategic Initiative on Coastal and Marine Spatial Planning (SICMSP) (ToR e)

The WGMASC 2010 report gives an overview of information gathered over the years by WGMASC that are relevant to the subject (e.g. the ToR that ended in 2009 on a recommended framework for the integrated evaluation of the impacts of shellfish aquaculture activities in the coastal zone and that is now submitted as a publication with the title: "An Ecosystem-Based Framework for the Integrated Evaluation and Management of the Impacts of Shellfish Aquaculture Activities in the Coastal Zone"). In addition, the social dimension was further expanded and several recommendations for further issues to address were given.

At our 2011 meeting the group felt that the socio-economic dimension is best treated by the newly established Study Group on Socio-Economic Dimensions of Aquaculture (SGSA). Their ToR a) of 2011 is "Reviewing the progress on how to evaluate the direct and indirect socioeconomic consequences of the use of marine space by aquaculture". The Working Group for Marine Planning and Coastal Zone Management (WGMPCZM) has the best position to play a leading role in the Strategic Initiative on Coastal and Marine Spatial Planning.

Future contributions of WGMASC can be providing examples and case studies to the SICMSP. In addition, expertise of the group can be used when information is needed on where shellfish can be grown and what the environmental impacts of those activities are. Updating available knowledge on decision support tools that can be used in spatial planning of aquaculture areas is another contribution. The WGMASC awaits more specific requests from the SICMSP.

7.1 Recommendation

WGMASC see on opportunity to interact with SICMSP. The group has expertise on spatial planning of aquaculture: e.g. how to define the best locations to grow shellfish and ensure that planning applications are processed efficient and effectively (GIS based tools as an aid in the development of management areas). Furthermore, case studies can be provided dealing with the relation between aquaculture and coastal and marine spatial planning. WGMASC recommends that SCICOM discuss this with SICMSP.

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

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 the table was reviewed and modified (Table 1).

Table 1. Overview of EGs with which WGMASC envisage possible future interactions.

	Interested in joint activity?	Joint meeting potential?
SGSA	Y	Y
WGEIM	Y	Y
WGPDMO	Y	N
WGAGFM	Y	N
WGMPCZM	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 (SGSA), because many of the shellfish aquaculture issues have a socio-economic dimension.

Because of overlap in ToRs it is planned to have a joint meetings with Working Group on Environmental Interactions of Mariculture (WGEIM) every 3 years.

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 an Annual Science Conference, were identified with WGPDMO and the Working Group on Application of Genetics in Fisheries and Mariculture (WGAGFM).

The Working Group for Marine Planning and Coastal Zone Management (WGMPCZM) is relevant to WGMASC, particularly sustainability indicators and Marine Protected Areas. WGMASC deals with aquaculture aspects of MPCZM.

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 WGMPCZM. Distributing our reports directly to those groups may stimulate cooperation.

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Annex 2: Agenda

AGENDA ICES WGMASC 2011 Annual Meeting

Ifremer, La Trinité sur Mer, France

<u>Tuesday 5 April</u>

09:00 Housekeeping information from Joseph and installation of computers

09:30 Welcome coffee from Ifremer by Edouard Bédier director of the station Ifremer of La Trinité sur Mer

10:00 Introductions and update on ICES activities – Pauline Kamermans

- General discussion of ICES activities
- Draft publications (see titles below)
- Adoption of agenda

11:00 Plenary to develop work plan, identify subgroups, subgroup leaders and rapporteurs

12:30 Lunch

13:30 Subgroup sessions (ToR = WGMASC Term of Reference):

- 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 Continue ToR subgroup sessions

18:00 – 19:00 Presentations by Nathalie Cochennec (IFREMER) on oyster mortalities in France the last 3 > years

19:00 – 20:00 : aperitif (chez Joseph)

20:30 Dinner Fromentine, Auray-Saint-Goustan

<u>Wednesday 6 April</u>

09:00 Plenary – brief overview of work status

09:30 Plenary discussion on:

- ToR e: *Contributions of WGMASC to the Strategic Initiative on Coastal and Marine Spatial Planning (SICMSP)*
- ToR f: *Collaboration with other EGs in relation to the ICES Science Plan*

10:30 *Health Break*

11:00 Reconvene ToR subgroup sessions

12:00 Lunch including small excursion: oyster establishment and beach walking near oyster concessions (Le Pô, Carnac)

15:00 Reconvene ToR subgroup sessions

18:00 Short update by David Fraser (Fisheries Research Service Marine Laboratory) on the UK situation regarding OsHV-1 uvar and biosecurity plans in relation to shellfish farm sites

And a request from Kris van Nieuwenhoven (ILVO) related to DG Environment Regulations for Aquaculture in Natura 2000 areas.

18:30 Election of a new Chair for a three-year mandate

20:00 Dinner offered by our host (restaurant "La Côte, Carnac)

Thursday 7 April

09:00 Plenary discussion of

- ToR a: *Emerging shellfish aquaculture issues and science advisory needs*
- Discussion on any new Terms of Reference
- Discussion on Theme Session for Annual Science Conference in Bergen in 2012

11:00 *Health Break*

11:30 Continue ToR subgroup sessions to finish 1st draft (upload documents) and reading text of other subgroups

12:30 **Lunch**

13:30 Reading text of other subgroups

15:00 Plenary Session:

- Review and discuss 1st draft of WGMASC report
- Discussion and drafting of recommendations
- Date and location of the next meeting

18:00-19:00 Discussion with shellfish producers from South Brittany

20:30 Dinner

Friday 8 April 2011

Excursion 7:30-13:00 to Ile aux Moines and Golfe du Morbihan

Annex 3: WGMASC draft terms of reference for the next meeting

The **Working Group on Marine Shellfish Culture** (WGMASC), chaired by Pauline Kamermans, The Netherlands, will meet in VENUE (to be announced), 27–30 March 2012 (dates to be confirmed) 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 of site selection criteria in molluscan aquaculture with particular reference to accessing and developing offshore facilities.

c) Review and assess: the potential for transfer of non-indigenous species and diseases; the potential genetic implications for wild stocks; the impact on recruitment to existing stocks by large-scale transfers, and scientific tools for decision support on cultured shellfish transfer issues.

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

e) Develop a workplan for new Terms of Reference.

WGMASC will report by 5 May 2012 (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. 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) Spatial competition for aquaculture sites along coastal seas has encouraged the initiative of moving shellfish aquaculture into the open ocean at exposed sites within the EEZ. 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 analysing the overall health status 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 operation on offshore shellfish farming, both for spat collection or for ongrowing 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. The Chair of WGMASC will cross-reference all work with SCICOM and relevant Working Groups. Term of Reference c) Different shellfish life stages are transported from hatcheries and field sites to new culture sites, and often cross international boundaries, with potential implications for the introduction of non-indigenous species and diseases and the potential for interactions with wild stocks (impact on recruitment, genetic composition, diversity and polymorphism, and physiological and morphological traits). There is a need to identify the significance of shellfish relocations on the geographic distribution of wild stock traits. Scientific tools for decision support on cultured shellfish transfer issues should be reviewed and assessed. The Chair of WGMASC will cross-reference all work with the Chairs of the WGEIM, WGPDMO and WGITMO. Term of Reference d) Climate variability affects the recruitment and production of important commercial species and affects site suitability for shellfish culture. Increased knowledge of the effects of climate change on shellfish culture is needed to predict and assess impacts on aquaculture distribution and production. The Chair of WGMASC will cross-reference all work with the Chair of the WGEIM. Term of Reference e) In 2012 a number of ToRs will be finished. Therefore, it is suggested to develop a workplan for new ToRs that will be stared in 2013. Topics mentioned under ToR a) will be considered.
Resource requirements	The research programmes which provide the main input to this group are 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, 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. WGMASC see on opportunity to interact with SICMSP. The group has expertise on spatial planning of aquaculture: e.g. how to define the best locations to grow shellfish and ensure that planning applications are processed efficient and effectively (GIS based tools as an aid in the development of management areas). Furthermore, case studies can be provided dealing with the relation between aquaculture and coastal and marine spatial planning. WGMASC recommends that SCICOM discuss this with SICMSP.	SCICOM, SICMSP, WGMPCZM
2. WGMASC recommends to propose a Theme Session for the 2012 ASC in Bergen on *Emerging diseases, fouling and predators in shellfish aquaculture* together with WGEIM (Working Group on Environmental Interactions of Mariculture), WGPDMO (Working Group on Pathology and Diseases of Marine Organisms) and WGAGFM (Working Group on Application of Genetics in Fisheries and Mariculture).	WGEIM, WGPDMO, WGAGMF, SCICOM
3. ICES activities related to climate change issues are inherently linked and the WGMASC supports the SSICC recommendation for ICES to adopt a formal resolution from ICES governing bodies to establish such a cross-cutting programme on climate change. In the interim, the WGMASC will continue to review outputs from other relevant expert groups and to integrate these results into our activities. An integrated approach to addressing aquaculture aspects of climate change may be for the WGEIM to expand upon the current work of the WGMASC. Key members of the WGEIM are also invited to actively participate in WGMASC meetings where this ToR is addressed.	SCICOM, WGEIM, WGFCCIFS, SSICC
4. The research effort on the effect of climate change on cultured shellfish species is largely in its infancy, but is increasing rapidly. Rather than continue to simply review project results as they become available, we recommend that the WGMASC focus future activities on the provision of advice on related research and management priorities. However, it will be important to continue to keep abreast of research relating to the effects of climate change on shellfish aquaculture.	WGMASC, SCICOM