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Executive summary

The Seventh meeting of the Working Group on Marine Shellfish Culture (WGMASC; Chair: Pauline Kamermans) was held on 7–9 April 2009 and was attended by 9 participants from 7 countries. The objective of the meeting was to work on the Terms of Reference that were decided upon in 2008. The ToRs were addressed separately within subgroups, followed by plenary sessions where subgroup activities were discussed by the full WGMASC.

ToR a) The following emerging shellfish aquaculture issues were identified: - Restocking of cultured shellfish, - Organic certification of cultured shellfish, - Social conflicts between stakeholders involved with shellfish cultivation, - The correct species identification of cultured shellfish (Section 3).

ToR b) An integrated ecosystem approach to aquaculture (EAA) management has been defined as a strategy for the integration of aquaculture within the wider ecosystem in such a way that it promotes sustainable development, equity, and resilience of interlinked social and ecological systems. The DPSIR (Driving Forces-Pressures-State-Impacts-Responses) framework is recommended as the basis for an EAA as it identifies environmental problems, their causes and solutions, and recognizes important linkages between ecological and socio-economic systems. Potential ecological indicators were reviewed that inform about ecosystem status and the impact that aquaculture activities may have on ecosystems. Indicator selection criteria were provided. It is recommended that an EAA be based on a tiered monitoring approach that is structured on the principle that increased environmental risk requires an increase in monitoring effort. It is recommended that regulatory decisions be based on partitioning the range of indicator variation into several threshold categories to permit implementation of mitigation measures prior to reaching an unacceptable ecological state (Section 4).

ToR c) and d) The introduction and translocation of live shellfish from hatcheries and field sites around the world can involve the introduction of non-indigenous species, diseases, parasites and harmful algae. Potential implications to wild and cultured stocks include impacts on recruitment, reduced fitness, increased competition and predation, and change in genetic composition, diversity and polymorphism. The WGMASC focuses on the significance of bivalve aquaculture transfers to resident wild and cultured bivalve stocks. Information is gathered on guidelines for and records of the transfer of cultured shellfish in ICES countries. Potential implications and effects of the introduction and transfer of alien species were reviewed together with the identification and ranking of risks. Recommendations were made to help minimize impacts, to guide farmers and policy-makers – in support of the development of policy decisions on cultured shellfish transfers (Section 5).

ToR e) The review on the state of knowledge of the evidence of and effect of climate change on shellfish aquaculture distribution and production in ICES and countries worldwide was continued. Climate changes will ultimately determine which shellfish species are suitable for farming in a given region and will indirectly influence other factors that influence aquaculture (e.g. primary production, harmful algal blooms, oxygen levels, sea level, ocean acidification, weather extremes). It is recommended to closely link the knowledge and advice generated under ToR e with all relevant ICES activities on related subjects by WGEIM, SGCC and WGFCCIFS (Section 6).

1 Opening of the meeting

The ICES Working Group on Marine Shellfish Culture [WGMASC], chaired by Pauline Kamermans (the Netherlands), held its seventh meeting in Bremerhaven, Germany from 7–9 April 2009 at the Alfred Wegener Institute (AWI). It was attended by nine members (see Annex 1).

The meeting was opened at 9.30 am Tuesday 7 April with the host Bela Buck giving housekeeping information and Allan Cembella welcoming the group at AWI. The Chair thanked the hosts for their hospitality. Then she welcomed the members to the meeting and thanked their respective institutions for allowing time and money to participate. She also informed that Kris Van Nieuwenhove was now appointed as a “common member” to the group. It was noted that the representation of members from the American side of the North Atlantic was low (only one member from Canada) and some discussion on this topic followed. The last few meetings were held in Europe. In addition, the common interests of the WGMASC and the Working Group on Environmental Interactions of Mariculture (WGEIM) were seen as a possible cause. That group contains a lot of North American members and as a result meets more often on that side of the Atlantic. Terms of Reference they work on include: (ToR a) sustainability indices proposed for mariculture activities, outputs of integrated aquaculture projects, (ToR d) review the use of seed stock quality criteria in mariculture and their applications in terms of ecological performance, and (ToR e) potential impact of climate change on aquaculture activities, which relate strongly to the WGMASC ToRs. It was felt by the group that more coordination and interaction between the work of both groups is needed to avoid overlapping of the tasks that need to be worked on.

The Chair reported on the recent changes in the ICES structure. The Mariculture Committee has ceased to exist. Instead the Working Groups, or Expert Groups, report to the newly installed SCICOM. Attention was given to the Science Plan. The Chair noted that the Terms of Reference that WGMASC is working on fits well within the first thematic area (**Understanding Ecosystem Functioning**). Specifically the research topic *Climate change processes and predictions of impacts*, our group focuses on climate change effects on aquaculture (ToR e); and *Biodiversity and health of marine ecosystems*, our group focuses on tools and indicators to evaluate the impacts of shellfish aquaculture activities in the coastal zone on ecosystem status and quality (ToR b). In addition, the work of WGMASC also falls within the second thematic area (**Understanding Interactions of Human Activities with Ecosystems**). Specifically *Carrying capacity and ecosystem interactions associated with mariculture*, our group completed a report in 2005 on the standard methodologies used to measure performance indices as related to examining the carrying capacity of the growing area and organized a joint WGEIM and WGMASC Theme Session on “Ecological Carrying Capacity in Shellfish Culture” that was held at the ICES ASC 2008 in Halifax (see Annex 2); and *Introduced and invasive species, their impacts on ecosystems and interactions with climate change processes*, our group looks into the significance and implications to wild stocks of bivalve aquaculture transfers between sites/countries. And finally, the third thematic area (**Development of options for sustainable use of ecosystems**) is touched upon in the Terms of Reference of the WGMASC. Specifically the research topic *Marine spatial planning*, our group worked on a sustainable aquaculture framework and the development of tools and indicators to evaluate the impacts of shellfish aquaculture activities in the coastal zone on ecosystem status and quality; and *Contributions to socio-economic understanding of ecosystem goods and services, and forecasting of*

the impact of human activities, research topics dealt with by our group relates to how socio-economics and the respective institutional arrangements drive aquaculture activities and their impact on society and the ecosystem (ToR b).

2 Adoption of the agenda

The Agenda (see Annex 3) was formally adopted. A general discussion on plans for each WGMASC Term of Reference was held. The WGMASC decided to continue the past practise 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 acted as Rapporteur for preparing draft reports from the work of subgroups and report on their group's activities during plenary sessions.

Since the group was only nine members the ToRs were critically reviewed to see how the work could be organized best. There were no new ToRs in 2009; all of the ToRs had been worked on in 2008. The only change is that ToR c) was split into two subjects, one focussing on records and guidelines involving bivalve aquaculture transfers (ToR c) and the other dealing with the implications of those transfers for wild bivalve stocks and scientific tools for decision support (ToR d). As in other years it was decided to address ToR a) (*identify emerging shellfish aquaculture issues and science advisory needs*) in plenary sessions. ToR b) (*a framework for the integrated evaluation and management of the impacts of shellfish aquaculture in the coastal zone*) was started in 2006 and is reaching its completion. The subgroup leader for this ToR was Peter Cranford. ToRs c) and d) (*aquaculture transfers between sites/countries – guidelines and records (ToR c) and impact on wild stock (ToR d)*) was started in 2008 as one ToR. Both concern bivalve aquaculture transfers and are closely related. Because of the small size of the group it was decided to combine the work on them. Subgroup leader for these ToRs was David Fraser. Since the group was too small to take on more ToRs it was decided to have only a plenary discussion on ToR e) (*effects of climate change on shellfish aquaculture*).

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

The purpose of this ToR was to briefly highlight new and/or important issues that may require immediate additional attention by the WGMASC and/or other Expert Groups. One high priority issue identified in the 2007 and 2008 WGMASC reports is offshore-related shellfish culture. This is now proposed as a new ToR to be addressed in 2010 (ToR b in Annex 4). The following emerging shellfish aquaculture issues were identified in 2009 (not listed according to priority):

- Restocking of cultured shellfish is practised in the United States for the American oyster. Its main purpose is restoration. Restocking, or rebuilding of spawning biomass, for aquaculture purposes may be a solution for the European oyster *Ostrea edulis*. This species became extinct in a number of areas as a result of human activities. It is a high valued species for fisheries and aquaculture. Restoration of the native population may not only benefit aquaculture, but it can also increase the value of the ecosystem. Identifica-

tion of the right conditions for restocking and the development of a protocol is needed.

- Sustainability issues related to consumption of cultured shellfish receive a lot of attention presently. In response to consumer requests for organic products organic certification of cultured shellfish is starting. Shellfish make an excellent candidate for an organic product as it does not need input of feed other than naturally occurring phytoplankton and can be produced locally. In addition, cultured shellfish do not only represent a valuable food product, during their life in the coastal zone they also have a role in ecosystem services such as reducing nutrients in the water column and acting as a carbon sink. Furthermore, shellfish cultivation can enhance alternative livelihoods in rural areas and provide social welfare. However, shellfish cultivation can have adverse effects on the ecosystem, such as bottom disturbance when dredging for seed, enhanced deposition of organic material in local areas and reduction of the carrying capacity for other filter feeding organisms. A variety of organizations use different standards for organic certification. These need to be evaluated and unresolved questions need to be identified and addressed.
- Shellfish cultivation is faced with increased social conflicts between stakeholders (farmers, nature conservationists, recreation, and fisheries). For example in the Netherlands, the use of mussel seed capture systems is promoted as an alternative for bottom dredging. But the supports of the capture systems are floating on the water surface which affects the landscape and the space for recreation and fisheries. These types of interactions make shellfish culture an excellent example for Integrated Coastal Zone Management (ICZM). Planning tools and alternative solutions need to be reviewed. How can we evaluate effects of new established marine management strategies such as the marine spatial planning act? What are indicators of the status of social perception of shellfish culture that can help in avoiding conflicts? How do social values and administrative organizations in different countries/regions affect trends in the intensity, methodology, structure and type of aquaculture?
- The correct species identification of cultured shellfish is not always available. In addition, there is a discussion on the reliability of tools and methods for genetic confirmation of species identification of shellfish. A review of current methods and recommendations for species identification are needed. The right species identification is important for commercial purposes as well as, for disease control and management. E.g. introductions of closely related species that can produce infertile hybrids should be avoided.

3.2 Recommendation

The WGMASC recommends to continue ToR a to identify and report on emerging shellfish aquaculture issues and related science advisory needs for maintaining the sustainability of living marine resources and the protection of the marine environment.

4 Complete the development of a recommended framework for the integrated evaluation of the impacts of shellfish aquaculture activities in the coastal zone (ToR b)

4.1 Background

Aquaculture is the fastest growing food-producing sector in the world and is expected to continue to grow and compensate for the predicted global shortage of supply from capture fisheries and the demands of society. Although there is a clear need for the continued worldwide expansion of aquaculture to fill this gap, this development needs to be promoted and managed in a responsible manner that minimizes negative environmental impacts. To ensure that human activities are carried out in a sustainable manner, international maritime policies (e.g. Canadian *Oceans Act* and EU *Water Framework* and *Marine Strategy Directives*) include as essential components; 1) a knowledge-based approach for decision-making, and 2) an ecosystem-based approach for integrative management.

An ecosystem approach (EA) may be defined as "a comprehensive integrated management of human activities based on the best available scientific knowledge of the ecosystem and its dynamics, in order to identify and take actions on influences that are critical to the health of ecosystems, thereby achieving sustainable uses of ecosystem goods and services and maintenance of ecosystem integrity" (Rice *et al.*, 2005). The Convention of Biological Diversity defined EA as a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way (UNEP/CBD/COP/5/23/ decision V/6, 103–106). An ecosystem approach for aquaculture (EAA) has been defined as "a strategy for the integration of the activity within the wider ecosystem in such a way that it promotes sustainable development, equity, and resilience of interlinked social and ecological systems" (Soto *et al.*, 2008). According to GESAMP (2007), an ecosystem approach to aquaculture strives to balance diverse societal objectives. EAA applies an integrated approach to aquaculture by taking account of the knowledge and uncertainties of biotic, abiotic and human components of ecosystems, including their interactions, flows and processes within ecologically and operationally meaningful boundaries. The FAO/Universitat de les Illes Balears Expert Workshop in Palma de Mallorca, Spain in 2007 recommended that the sustainable development of aquaculture should be guided by the following key principles. First, aquaculture should be developed in the context of ecosystem functions and services with no degradation of these beyond their resilience capacity. Second, aquaculture should improve human-well-being and equity for all relevant stakeholders. Third, aquaculture should be developed in the context of (and integrated to) other relevant sectors. Three scales/levels of EAA application have also been identified as the farm, the waterbody and its watershed/ aquaculture zone, and the global, market-trade scale. An ecosystem approach to the management of shellfish aquaculture should follow these same definitions and principles.

A goal of aquaculture management is to have tools available that can predict and measure the capacity of an area to support the cultured species. There are many components and tools that need to be developed and integrated into an ecosystem management framework for the evaluation of shellfish aquaculture impacts on the coastal zone. Components include: hazard identification; environmental exposure and risk assessments (including predictive modelling); risk management; cost-benefit analysis; environmental indicator monitoring; impact management based on indicator threshold values (environmental targets); implementation of effective mitigation

measures; decision support tools for responsive ecosystem management; and communication. With the development of the ecosystem approach to providing advice for the management of marine ecosystems, there has been a change in farm management beyond the recent focus on the development of tools for determining the maximum sustainable yield of the culture. This “production carrying capacity” approach reflected an economic and farm management perspective to aquaculture management. The present focus on ecological sustainability and EA requires consideration of significant changes in ecological energy flow, material fluxes, and the structure of the foodweb. These considerations are relevant to determining the “ecological carrying capacity” of an area for aquaculture development. The ecological carrying capacity can be defined as the level of culture that can be supported without leading to significant changes to ecological processes, species, populations or communities in the growing environment (Gibbs, 2007).

A global activity related to the development of an ecosystem approach for aquaculture is the creation of performance-based standards that are linked to certification schemes designed to minimize the key social and environmental issues associated with shellfish farming while permitting the industry to remain economically viable. It is recognized that the implementation of certification schemes helps the industry sector to work toward more sustainable aquaculture, including reduced impacts. Certification schemes relevant in some way to aquaculture have been reviewed by Funge-Smith *et al.* (2007) and the World Wildlife Fund (WWF, 2007). Organisations active in this field include the FAO, WWF, Friend of the Sea, Naturland, Global Gap, and Aquaculture Certification Council. The Marine Stewardship Council has recently decided to stop working on aquaculture certification. The WWF has identified key environmental and social issues related to mollusc production and is currently drafting certification criteria for shellfish aquaculture to reduce each issue. The underlying principle of certification is that a fully independent body from the production sector should be responsible for certification. Performance-based standards developed by the WWF will be given to a new organization (Aquaculture Stewardship Council) that will be responsible for working with independent, third party entities to certify farms that are in compliance with the standards.

The FAO has recently produced guidelines (FAO, 2007), intended for the production of improved finfish and shellfish aquaculture certification schemes that comply with the main principles of the ecosystem approach. The FAO has specified certification standards named HACCP (Hazards Analysis and Critical Control Point) which are the core of several national legislations across Europe and the United States. However, as the HACCP does not consider social and environmental impacts, it is not really relevant to the implementation of an EBM framework. To summarize, certification schemes for shellfish culture need to be improved to cover all the aspects of ecosystem based management, including considerations of the social, economic and environmental impact of shellfish culture.

A recurring bottleneck to the establishment of an operational framework for managing aquaculture is the need to define an “unacceptable” impact. Although science has an important role in advising managers and policy-makers on the ecological consequences related to available management options, this decision needs to be made within an integrated framework that is both science- and ecosystem-based, but which also incorporates societal values. Our perceived role as scientists in the development of a recommended ecosystem approach for managing shellfish aquaculture impacts is to provide science-based advice and recommendations on:

- 1) Effective performance-based approaches and indicators for characterizing ecosystem status and impacts of a highly diverse shellfish aquaculture industry;
- 2) Identifying the potential consequences to coastal marine ecosystems from changes in ecosystem status and impacts and identifying related thresholds of potential public concern);
- 3) Identifying effective measures for preventing or mitigating any impacts from shellfish aquaculture; and
- 4) Reviewing and assessing available management frameworks that facilitate ecological sustainability by considering their capacity to incorporate an ecosystem perspective, societal values and the economic viability for industry.

It is not solely the responsibility of ecological scientists to determine a framework for the integrated evaluation of the impacts of shellfish aquaculture activities in the coastal zone. Socioeconomic science considerations are paramount in setting critical decision criteria (e.g. what constitutes an unacceptable impact?). Although socio-economic issues were generally considered outside the scope of our activities, deliberations on many components of a pragmatic shellfish aquaculture management framework required discussion of costs to industry and “potential” public concerns. To help define what level of impacts are acceptable, socio-economical sciences can help in clarifying the values and expectations of different groups, and contribute to the economic evaluation of environmental services. Furthermore, environmental conservation and protection and other legislations pertaining to the utilization of coastal areas are clearly important considerations for the selection of indicators, and particularly for the setting of regulatory triggers/thresholds.

This report is structured to address the Term of Reference by starting with a brief review of the potential ecological interactions with shellfish aquaculture. We then consider indicator-based management frameworks that deal with the concept of driving forces, impacts and responses, and impact assessment approaches and tools. More specific shellfish aquaculture management issues are then addressed, including identification of general and recommended indicators related to specific environmental, and to some extent socio-economical, effects from shellfish culture operations, potential applications of modelling approaches, a discussion on thresholds of ecological and potential public concern, monitoring approaches for a diverse industry, impact mitigation measures, responsive management and decision support systems. The recommended management framework is then reviewed in the context of current international legislations affecting aquaculture to evaluate the capacity to address a wide range of regulatory criteria.

4.2 Ecosystem Interactions with Shellfish Aquaculture

A fundamental understanding of the influence of this expanding industry on coastal ecosystems, as well as interactions with other anthropogenic stressors, is needed for developing strategies for sustainable aquaculture and integrated coastal zone management. The culture of bivalve molluscs and their associated rearing structures has the potential for impact the environment in numerous positive and negative ways (Dame 1998; Souchu *et al.*, 2001; Christensen *et al.*, 2003; Newell 2004; Cranford *et al.*, 2006 and 2007). The identified negative effects are generally linked to: the consumption of suspended particles; to increased sedimentation as a consequence of the production and release of biodeposits (faeces and pseudofaeces) that may impact

sediment biogeochemistry and the structure and composition of benthic and pelagic communities; and to effects on nutrient dynamics from ammonia excretion and the translocation of suspended matter from pelagic to benthic compartments. The extent and magnitude of ecological interactions with mussel culture are always site-specific with vulnerability depending on factors controlling food consumption and waste production (e.g. intensity of culture and food supply) and waste dispersion. Waste dispersion rate largely determines the capacity of the local environment to prevent excessive food depletion and benthic impacts and is controlled by physical factors (e.g. circulation, bathymetry and coastal morphology). These impacts are related to the physiological interactions of bivalves with their surrounding environment, as illustrated in Figure 4.2.1.

Filter-feeding by mussels naturally results in some local reduction (depletion) of their food supply (suspended particulate matter). If the mussel culture is consuming seston faster than they can be replaced by tidal flushing and phytoplankton growth, then the mussels will become food limited and mussel production will be less than maximal for that site. If the spatial scale of phytoplankton depletion expands outward from the farm(s) to include a significant fraction of the coastal inlet, then this effect on the base of the marine foodweb generates ecological costs to other components of the ecosystem. The shellfish biofilter selects a specific size-range of food particles and small phytoplankton (picophytoplankton) that cannot be captured may dominate in areas where large-scale food depletion occurs (Olsson *et al.*, 1992, Prins *et al.*, 1998, Cranford *et al.*, 2006). Shallow, poorly flushed embayments in Atlantic Canada and in the Mediterranean that support extensive shellfish aquaculture have been shown to have an extremely high abundance and proportion of picophytoplankton (Vaquer *et al.*, 1996, Souchu *et al.*, 2001, Cranford *et al.*, 2008). In general, benthic impacts are well known compared with pelagic effects and relatively easy to monitor with current sampling and analytical techniques. However, recent technological advancements have improved our understanding and capacity to monitor the magnitude and scales of pelagic effects (e.g. Cranford *et al.*, 2008).

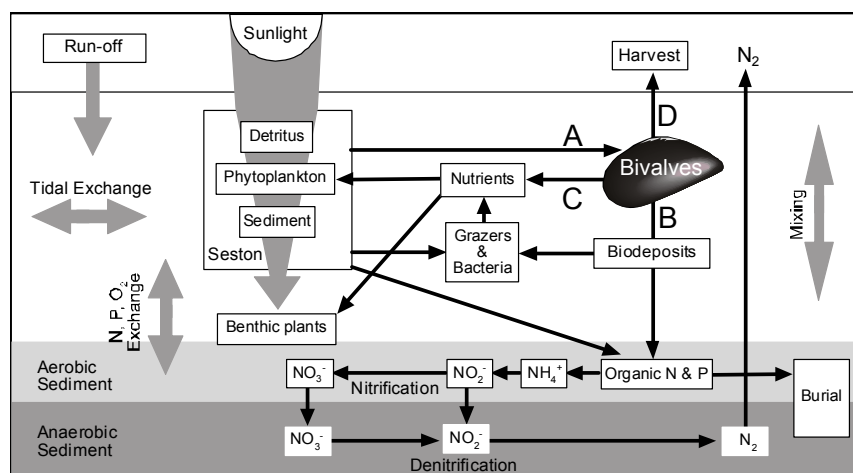


Figure 4.2.1. Conceptual diagram of shellfish (bivalve) aquaculture interactions in coastal ecosystems related to: (A) the removal of suspended particulate matter (seston) during filter feeding; (B) the biodeposition of undigested organic matter in faeces and pseudofaeces; (C) the excretion of ammonia nitrogen; and (D) the removal of materials (nutrients) in the bivalve harvest (from: Cranford *et al.*, 2006).

4.3 Ecosystem Based Management Frameworks

4.3.1 The Different Indicator Frameworks

Recommending the use of ecosystem status and impact indicators specific to shellfish aquaculture should be considered in the perspective of a wider ecosystem approach for managing shellfish culture. Documenting the impact of shellfish culture on the marine environment through the use of indicators should be completed with the implementation of recommendations on specific management methods, on assessment, monitoring and scientific research, and on methods of measuring progress towards implementation. Considering the variable impact of shellfish aquaculture on marine environments, a management framework based on the type of shellfish culture may be relevant. To cope with the particular aspects of the impact of shellfish culture, it is suggested that an environmental framework includes the following themes, which correspond to the main impacts observed in marine environments:

- 1) impact on seabed geophysical properties, geochemical processes and the structure and ecological role of benthic flora and fauna (i.e. indicators of seabed status and benthic performance),
- 2) water column interactions with shellfish culture (i.e. effects on water quality, on the pelagic ecosystem structure and function, and on hydrodynamic),
- 3) the cumulative ecological effects of any pelagic and benthic interactions with shellfish culture, including wild fish concentrations (Clynick *et al.*, 2008), the role of fouling communities, and indirect effects on zooplankton and fish populations,
- 4) potential genetic implications of culture activities,
- 5) the synergistic and/or antagonistic effects of all anthropogenic activities in the region, and
- 6) socio-economics aspects, including environmental costs.

Indicators are often presented within already established frameworks and these are often built in a given social context (Olsen 2003). Indicator selection also depends on the spatial or economic scale considered (Spangenberg, 2002; Rochet and Trenkel, 2003). Indicator frameworks provide the means to structure sets of indicators in a manner that facilitates their interpretation and can aid the understanding of how different issues are interrelated (Segnestam, 2002). Indicators are also usually needed for many aspects of a problem or issue, and the framework selected ensures that all of those aspects have been taken into account. Three different types of frameworks for presenting indicators are generally recognized (OECD 2000):

- 1) *Project-based frameworks*, referred to as the Input-Output-Outcome-Impact framework, are used in the monitoring of the effectiveness of projects designed to improve the state of the environment.
- 2) *Driving Forces-Pressure-State-Impact-Response (DPSIR) frameworks* originally developed by the Organisation for Economic Cooperation and Development (OECD) for national, regional and international level analyses, are now in use in the European Environment Agency and by other international institutions. Many studies on indicators refer to this framework.
- 3) *Frameworks based on environmental or sustainable development themes*. Examples include: pelagic/benthic; communities and species; flows of carbon/nitrogen; loss in diversity; economic damage; intensive vs. extensive

aquaculture; open or closed environments; hydrodynamics, damages to, and remediation of environmental, economic, and social cost.

4.3.2 The DPSIR framework

A management framework that identifies environmental problems, their causes and solutions, and which recognizes important linkages between ecological and socio-economic systems is known as DPSIR (Driving Forces-Pressures-State-Impacts-Responses). The DPSIR framework (Figure 4.3.2.1) is used to organize multiple systems of indicators of sustainable development and, for example, has been applied by the European Environment Agency to manage the EU Water Framework Directive. The DPSIR framework allows coverage of a large spectrum of particular situations, as long as the environment is concerned. This framework was originally derived from the social studies and has subsequently been widely applied internationally, particularly for organising systems of indicators for managing environment and sustainable development. A full description is given by the Organisation for Economic Cooperation and Development (OECD). The first version of this framework is called the Pressure-State-Response (**PSR**) framework that states that human activities exert *pressures* on the environment, which can cause changes in the *state* of the environment. Society then *responds* with environmental and economic policies and programs intended to prevent, reduce or mitigate pressures and/or environmental impact.

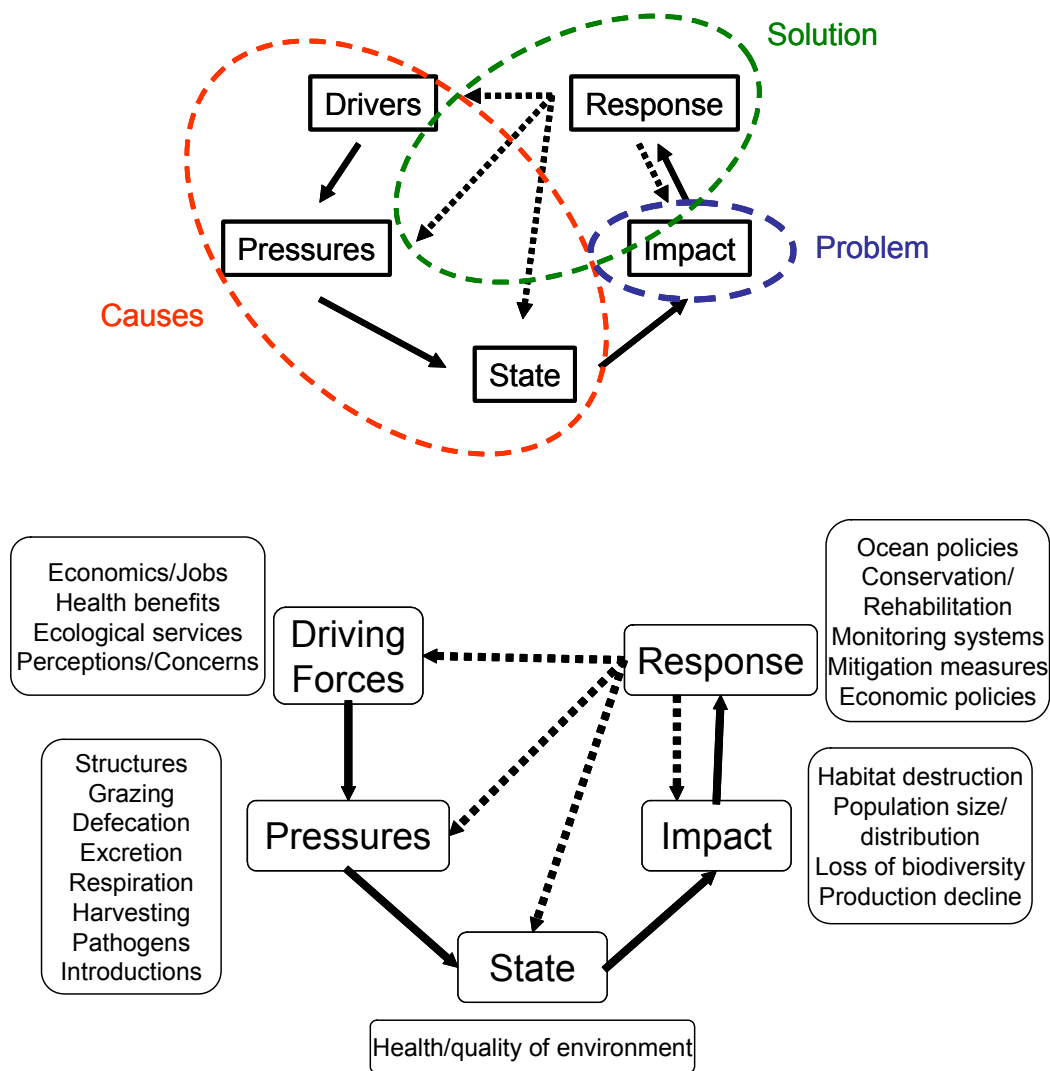


Figure 4.3.2.1. The DPSIR framework for integrating aquaculture, socio-economic and ecological interactions. Top: Components and functions of the DPSIR framework. Bottom: Factors and processes within the different components of the DPSIR framework related to shellfish aquaculture.

The first variation of the PSR framework replaced the pressure indicator category with a category of driving force indicators, creating a Driving Force - State - Response (DSR) framework. The driving force component includes human activities, processes and patterns that impact on sustainable development, and is intended to better accommodate socio-economic indicators. The second variation adds a category of impact indicators, transforming it into a Pressure-State-Impact-Response (PSIR) framework. The latest version, which has become widely employed, is the DPSIR framework (Figure 4.3.2.1). In this framework, the Driving Forces produce Pressures on the environment, which then degrade the State of the environment, which then Impacts on human health and eco-systems, causing society to Respond with various policy measures. The DPSIR framework provides a structure that describes the processes involved in integrated management issues (Figure 4.3.2.1). It has the capacity to be utilized in many different types of systems and it recognizes critical linkages between ecological and socio-economic systems that permit an analysis of the functioning of human/ecosystem interactions. The framework is often recommended for coastal zone management to identify the key factors and processes at different stages. The general DPSIR framework can be recommended as a basis for the assessment,

evaluation and operational management of the impacts of shellfish aquaculture activities in the coastal zone. DPSIR is a well developed, science-based framework rooted in human ecosystem thinking. It reveals aspects of environmental problems, their causes and remedies and can be used for focusing the developing of science methods to analyse aquaculture issues (ecological risk assessment, models, indicators, monitoring...).

When producing a set of indicators related to the impact of shellfish farms, most of these indicators are related to the State and Impact components. However, indicators are needed to monitor all the framework components for the integrated management of the linked ecosystem and socio-economic aspects of aquaculture.

4.3.3 Modelling and potential management role

Assessment of aquaculture has generally occurred at the farm scale by measuring the ecological 'footprint'. Extrapolating these effects up to any larger scale is considerably more complex and includes considering impacts of multiple farms and ecological interactions that are a function of bathymetry, farm proximity, circulation, and coastal morphology. Modelling permits an understanding of how all culture units interact over a scale relevant to coastal ecosystems. Modelling is often used as a tool to predict probable changes in environmental indicators and have been used to describe our understanding of environmental processes at work at farm to regional spatial scales. Types of models vary greatly in complexity from simple scaling exercises that compare flushing times to clearance times (e.g. Dame food depletion index) to energy or nutrient budgets, simplified to complex 2-D box models and 3-D finite element models coupled with hydrodynamic models. The ECASA project has identified a virtual toolbox containing, among other 'tools', a list of models such as ShellSIM, FARM, Longlines, DEB, and DDP, that can be used by operators and public environment managers to minimize the environmental impact from shellfish aquaculture operations. These models help maintain environmental quality and ensure the sustainability of sites and water bodies for aquaculture (www.ecasatoolbox.org.uk). Many models focus primarily on shellfish crop production and the influences of hydrodynamics, food availability and production, bivalve feeding physiology, and stocking density. The ability to predict the shellfish production carrying capacity for shellfish aquaculture is therefore well developed and has been applied in a wide range of ecosystems (reviewed by McKindsey *et al.*, 2006). Such models also provide information on some other community and ecological effects associated with any negative feedback on the culture.

The zone of potential benthic community effects from shellfish biodeposits may be predicted using particle tracking models, such as DEPOMOD (Cromeey *et al.*, 2002), that predict organic matter flux to the seabed (Chamberlain, 2002). Similarly, the potential ecological effects from mussel culture may be predicted using data-intensive nitrogen budgets, spatially explicit food depletion models and ecosystem models of varying complexity (Cranford *et al.*, 2007, Grant *et al.*, 2008). A study using a mass-balance approach and the Ecopath model concluded that the ecological carrying capacity of the study area, as indicated by the shellfish production level causing major changes in energy fluxes within the system's foodweb, occurred at production levels that are considerably less than those that exceed the production carrying capacity (Jiang and Gibbs, 2005). This is in general agreement with results presented by Cranford *et al.* (2007) who used a nitrogen budget and results from lower trophic level box model scenarios to demonstrate the dominant role of extensively cultivated mussels in controlling ecosystem functioning (Cranford *et al.*, 2007). Ecosystem models have also

been used to test scenarios of aquaculture pressure on water quality (Nobre *et al.*, 2005) and ecosystem productivity (Marinov *et al.*, 2007) within the DPSIR framework. Models/indices that focus on far-field effects (e.g. nutrient cycling, pelagic carrying capacity) can provide industry and ocean management with the tools to efficiently and comprehensively assess effects associated with shellfish culture activities within an ecosystem-based management framework.

The use of indicators to measure ecological conditions at a site prior to the initial development of shellfish culture has rarely been performed. The ability of models to estimate the difference between the observed situation in the presence of shellfish activity and the expected situation without the activity, within an expected level of confidence, is a potential solution to this management problem and provides discrimination between the suspected causative factor (shellfish culture) and other factors.

Models are useful within the DPSIR framework to identify indicators of ecosystem status and associated operational management thresholds, and therefore aid in the development of the decision-making process among regulators, developers and stakeholders (DFO, 2006). In many ecosystems where shellfish aquaculture is prominent, it is possible to utilize ecosystem models to;

- assess the potential impact of shellfish on the ecosystem state,
- define indicators based on predicted fluxes in order to summarize ecosystem properties (nutrient throughput, recycling and time-scales)(Smaal and Prins, 1998),
- compare ecosystems using the selected set of indicators,
- assess interactions between aquaculture and other human activities in the coastal zone (Cranford *et al.*, 2007),
- assess ecosystem functioning on the long term and determine if aquaculture ecosystem interactions interfere with other services provided by the ecosystem, and
- define ecological thresholds linked to the density-dependant effects of shellfish aquaculture.

Model-based indicators may be a cost-effective alternative to extensive field studies that may or may not be able to differentiate between anthropogenic impacts and the large variations that occur naturally. A number of countries have well-developed policies and procedures in place that utilize modelling tools for planning and monitoring as well as regulation of impacts from nutrient enhancement, organic waste deposition and the dispersion and deposition of medicines and chemicals (reviewed by Henderson *et al.*, 2001). However, the use of models for the regulation and monitoring of aquaculture has been restricted to finfish applications in a relatively small number of countries and model applications have been limited to site application assessments, the identification of holding capacity and the licensing of medicines (Henderson *et al.*, 2001). With respect to shellfish, the models that are in current use to predict production carrying capacity, food depletion and ecological interactions are only indirectly utilized in regulatory activities. However, predictions from models can be obtained quickly and are contributing to the movement from reactive to proactive management.

The final report of the MARAQUA project recommended greater use of modelling as a means to achieving best practice. MARAQUA suggested that “modelling can play a key role in monitoring the release of nutrients and organics; the dispersion of chemi-

cals to the seabed; the effects of structures on habitat change; in risk assessment of escaped fish impinging on the environment; and in assisting planners, producers and regulators in understanding the impacts of aquaculture in a way that will allow them to develop environmental management and sustainability strategies." Whereas several of these benefits are not relevant to shellfish culture (fate of chemical additions), ecosystem modelling of shellfish culture is believed to be at a more advanced state than for finfish, particularly with respect to predicting pelagic effects.

4.4 Indicators for the Integrated Evaluation of Shellfish Aquaculture Impacts

Indicators are developed as a way to assess and quantify changes, progress and improvements towards more sustainable development. Ecological indicators are selected and employed to communicate information about ecosystem status and the impact that aquaculture activities have on ecosystems to responsible authorities (aquaculture and regulatory managers and government policy-makers) and to the public. Ecological indicators can help describe ecosystem status, ecosystem health, environmental performance (also seabed or water column performance), and functional sustainability performance in a manner that can be understood and used by non-scientists to make management decisions (Rice, 2003, Gibbs, 2007). The indicators may be used for problem identification, planning, allocation of resources, policy assessment, etc. One of the important functions of indicators is that they can act as a bridge between science and policy. In the present case, the primary purpose will be for the ongoing evaluation of the sustainable development of shellfish culture operations. Gilbert and Feenstra (1993) identified four desired features of indicators:

- 1) the indicator must be representative for the system chosen and must have a scientific basis;
- 2) indicators must be quantifiable;
- 3) a part of the cause-effect chain should be clearly represented by the indicator; and
- 4) the indicator should offer implications for policy.

These features intersect with the principles of the DPSIR framework. More detailed characteristics, or criteria, for desirable global sustainability indicators are given by Liverman *et al.* (1988).

Some concepts from the sustainability literature are worth remembering when assessing the relevance of indicators in a given context. Several authors have pointed out that an indicator cannot usually be made from a simple parameter. A chemical measurement or abundance generally does not prove to be effective indicator. For example, an isolated winter measurement of chlorophyll *a* is not relevant to indicate the local level of eutrophication (Bricker *et al.*, 1999), whereas an extreme statistic computed from data sampled at high frequency in an exposed site at risk season will better reflect this phenomenon. Thus, as emphasized by Nicholson and Fryer (2002), the term "indicator" implies the relevance of the parameter, i.e. the linkage to the question or set of questions generating the need for the indicator(s). In the previous example, there is a direct relationship between chlorophyll *a* and coastal nutrient enrichment. The indicator-statistic, for example, a slope in Nicholson and Fryer (2002), and the associated metrics, i.e. the unit in case of a quantitative indicator, are necessarily parts of the indicator concept.

A parameter or set of parameters, or an "index" or a "score", are considered a good indicator only after it has been validated to effectively indicate what it was designed for. There are two nested conditions for this: (1) the appropriate mathematical ap-

proach must be defined that will transform quantitative or qualitative data into numbers that can be compared with the threshold values in a predefined classification system; and (2) the information collection process (i.e. sampling design), consistent with the former condition, must be precisely defined to provide reasonable statistical power for effectively detecting an impacted area. Gibbs (2007), in his review of indicators for suspended bivalve culture, noted that the indicators should identify where present levels of culture may be in relation to; the ability of the shellfish culture to control phytoplankton dynamics, and to the ecological and production carrying capacity within the growing region.

4.4.1 Potential Indicators for Shellfish Aquaculture

Indicator systems are seen as central tools for ecosystem-based fisheries management, helping to steer fisheries towards sustainability by providing timely and useful information to decision-makers. Without testing hypotheses about the links between policies and outcomes, however, indicator systems may do little more than promote *ad hoc* policies, possibly even prolonging the transition to sustainable (shellfish) fisheries (Rudd, 2004). Ideally, the indicator framework for integrative shellfish cultivation assessment should transparently encompass both driver-oriented pressure-state-response (DPSIR) frameworks and structurally oriented sustainable livelihood indicator frameworks, thus providing a platform for ecosystem-based fisheries management policy, experiment design and monitoring.

Indicators describing social-ecological system status and, more specifically, the impact of shellfish aquaculture on the coastal zone were compiled from different sources. Several European contracts were aimed at producing indicators related to the interaction of aquaculture (and shellfish culture) with the marine environment. Examples of attempts to compile indicators related with the sustainable development of marine aquaculture include the MARAQUA (www.lifesciences.napier.ac.uk/maraqua/), *Consensus* (www.consensus.org) and ECASA (www.ecasa.org) programs. The 2006 Canadian review of potential indicators and associated thresholds used an ecosystem approach to identify and recommend an indicator-based approach and environmental monitoring framework for managing shellfish aquaculture impacts on marine habitat (DFO, 2006; Cranford *et al.*, 2006; Chamberlain *et al.*, 2006). The review by Gibbs (2007) focuses on sustainability performance indicators based on bivalve aquaculture interactions in the water column (e.g. clearance efficiency, filtration pressure, regulation ratio, and depletion footprint). Potential indicators are presented according to a classical scheme including benthic, pelagic and socio-economic aspects of marine, coastal ecosystems.

4.4.1.1 Sediment indicators

The main impacts of shellfish aquaculture on the sediment are related to the deposition of shellfish faeces and pseudofaeces and other fall-off from the holding structures (shellfish and fouling organisms and their diodeposits), the resulting accumulation of organic matter, and its mineralization. Some indicators are intended to address the flux of organic matter to the sediment; some characterize the change in the sediment properties, while other indicators describe the biogeochemical processes associated with the ecological recycling of the organic matter. The following describes the available range of sediment indicators (in italics):

- *Sedimentation rates* as measured by sediment traps. The sediment traps facilitate measurements of the quantity and quality of particulate matter falling from shellfish culture, both in subtidal and intertidal environments.

Probably the simplest measurement of the impact of shellfish culture consists of quantitatively collecting the biodeposits produced by bivalves during a given amount of time. This is a measure of flux of sediment and organic matter to the seabed.

- *Sediment texture* (per cent sand-silt-clay) of the sediment is directly influenced by the bivalve culture. The particulate matter is either aggregated as pseudofaeces by the gills of the molluscs or egested as faeces which contain a significant amount of relatively fine mineral particles.
- *Total organic matter and organic carbon* in the sediment reflects the amount of organic matter within the sediment, a major part resulting from the biodeposition observed under the bivalve culture. This is usually measured in surficial sediment.
- *Total nitrogen and organic nitrogen* in sediment.
- *Total phosphorus* in surficial sediment.
- *Sediment carbon quality indicators* including % carbon, C:N ratio and the Rp index. This Rp indicator (Kristensen, 2000) is based on the ratio of a measure of the labile organic carbon, as estimated by the losses on ignition at 250°C, and a measure of the refractory organic matter, after ignition at 500°C, and seems to be sensitive to the molluscs biodeposition (ECASA results).
- *Redox and Eh in surficial sediment*. Low values of the redox potential are linked with the anaerobic degradation of the organic matter into the sediment. It is best measured through vertical profiles into the sediment, which allows the thickness of aerobic and anaerobic conditions to be determined, as related with the quantity of organic matter.
- *Total 'free' sulphides* in surface sediment, which is related to oxygen content and biodiversity (Hargrave *et al.*, 2008).
- *Dissolved oxygen consumption rate* in sediment is a measure of the degradation of the organic matter in the upper, oxic layers.
- Other measurements can be performed on the *pore water gradient of dissolved nutrients* produced during the oxidation process. These include ammonia, total nitrogen, total phosphorus, and sulphates.
- *Benthic/pelagic fluxes* of sulphate and ammonia.
- *Trace metals* in sediment under finfish farms have been observed to increase. As these products seem to originate in the food, their pertinence in the case of bivalve culture needs to be demonstrated.
- Some *biomarkers* are candidates as indicators of the impact of shellfish culture. Van Biesen and Parrish (2005) have shown that the mono-unsaturated fatty acid content is higher in sediment beneath fish farm. Again, this needs to be demonstrated for bivalve culture.
- *Chlorophyll and phaeopigments concentrations in surficial sediment* can be an indicator of the impact of shellfish farms in low energy environments. A fraction of the phytoplankton ingested by shellfish is not digested and can accumulate beneath the facilities on surficial sediments.
- *Nitrifier and denitrifier bacteria* population abundance and activity
- *Sediment profile imaging of sediment colour and organism distributions*. Vertical profiles images sediment beneath aquaculture operations displays changes

in sediment colour and organism distributions indicative of organic enrichment effects.

4.4.1.2 Benthic community indicators

The impacts on benthic communities of increased organic matter input to sediments, resulting from biodeposition, and the stress resulting from sediment habitat modification, oxygen deficiency and toxic effects of H₂S are well known (Pearson and Rosenberg 1978, Hargrave *et al.*, 2008). Hypoxic and anoxic conditions are created in surface sediments if oxygen consumption rates exceed the supply, which is limited by physical and biological factors that control sediment-water exchange. Based on these reviews, the macrobenthic community can be expected to exhibit the following responses to an increase in organic loading:

- a decrease in species richness and an increase in the total number of individuals as a result of the high densities of a few opportunistic species;
- a general reduction in biomass, although there may be an increase in biomass corresponding to a dense assemblage of opportunist species;
- a decrease in body size of the average species or individual;
- a shallowing of that portion of the sediment column occupied by infauna; and
- a shift in the relative dominance of trophic groups.

Many criteria have been used to identify indices of benthic community effects. This has led to different results in many studies and a high degree of complexity for decision-making. Consequently, the choice of indicators is related to the specific needs of regulators. Using the DPSIR framework as an example, benthic community indicators are more suited to monitoring aquaculture effects (Impact) than as a general indicator of changes in ecosystem health (State). The most common benthic community indicators (*italics*) are summarized as follows:

- *Diversity indices*: Many studies on the influence of shellfish farming use biodiversity indices (Shannon-Wiener diversity (*H'*) species richness (*d*)) to identify the intensity of changes. A meiofauna diversity indicator is under test by the research teams involved in the ECASA project. Diversity indices and biomass indicators should be interpreted with caution and studies should combine diversity indices with other indices (e.g. indicator species) to better identify changes.
- *Indicator species*: Highly polluted marine sediments are generally dominated by a few opportunistic macrofaunal species, such as *Capitella* sp., that are tolerant of high organic enrichment and low oxygen conditions. Other deposit-feeding polychaete taxa and large carnivorous nematode worms have been observed to dominate in enriched sites where Mollusca and Echinodermata are completely excluded. The monitoring for opportunistic, deposit feeding and scavenger species, which tend to increase in number under shellfish farms, appears to an effective approach.
- *Trophic indices*: In highly organically enriched areas, benthic communities are dominated by deposit-feeders and scavengers, at the expense of filter-feeders. The absence of suspension-feeders may be a good indicator of perturbation because organic debris has a smothering impact preventing suspension-feeders from thriving. The loss of bio-irrigating species (deep-burrowing infauna) could enhance the anoxic conditions caused by or-

ganic enrichment. These changes in species composition could occur before a significant change is measured in sediment chemistry. The *infaunal trophic index (ITI)*, and the definition of benthic trophic groups have been selected by the ECASA group to be representative of the impact caused by shellfish aquaculture on the trophic group characteristics of the macrofauna. The *AMBI indicator* is based on the relative proportion of ecological groups among a community and has been tested in various environments and polluted sites. While it is not specific to aquaculture impact, it proved to react properly in the presence of organic enrichment including those resulting from shellfish culture in confined areas (Muxica *et al.*, 2005; Callier *et al.*, 2008).

- *Index of Biotic Integrity (IBI)*: No studies on the effects of shellfish farming have used Integrated Biotic Indices. IBI is limited to the geographical areas where the tolerance list has been compiled.
- *Benthic similarity indices*: Comparison of community structure with similarity analysis is a sensitive indicator since it is possible to determine differences among sites even at low organic enrichment. This approach provides a reliable indication of impacts been control and farm sites, and along-transects leading away from farms.
- *A size-related indicator* has been proposed. It relies on the fact that most of the species tolerant of an organic enrichment belong to families such as the Spionidae, and have a small size. Therefore a differential sieving of the sediment sampled for macrofauna studies, on 1 mm and 0.5 mm sieves, would allow quantification of the relative contribution of the smaller individuals to the whole community.
- *Sulphur reducing bacterial mats*. The use of photograph and video monitoring of the seabed under and at the vicinity of aquaculture facilities also allows indicators to be calculated using image processing and statistical analysis (Cranford *et al.*, 2006).

4.4.1.3 Pelagic indicators

Shellfish aquaculture, under some conditions (largely related to hydrodynamics and shellfish stocking density), has been shown to alter many biological and chemical properties of the water column that control ecosystem structure and function. Owing to the movement of the water, these effects can be transported far-field, with the potential for a measurable impact at the coastal ecosystem scale (Cranford *et al.*, 2006, Gibbs, 2007). Several pelagic indicators (in italics) have been proposed to describe the change in lower trophic levels occurring during shellfish culture:

- Rapid, high resolution, synoptic surveys of the *phytoplankton biomass (chlorophyll a) depletion footprint*, resulting from bivalve grazing, can reveal phytoplankton depletion at the farm to bay scale (Cranford *et al.*, 2006, Gibbs, 2007 and references cited therein). This pelagic status indicator is also relevant to bivalve induced depletion of, and competition with, the zooplankton.
- *Shift in plankton size spectrum*: A potential consequence of size-selective food particle depletion by cultured shellfish is a significant change in the size structure of the microbial plankton community from larger phytoplankton to smaller picophytoplankton. Given the potential ecosystem consequences of a shift in the pelagic foodweb (e.g. shift in predator/prey

interactions), indicators of size spectrum changes (increased *picoplankton abundance and proportion of phytoplankton*) are perceived as being highly beneficial for use in monitoring programs in extensively leased shellfish aquaculture inlets (Cranford *et al.*, 2006). This recommendation was also related to the relatively low cost of analysis, the ease of data interpretation, and the fact that site-specific measurements of plankton community alterations generally reflect conditions over much larger scales of impact.

- A greater *abundance of naturally occurring bacteria* can occur as a result of remineralization of organic matter in shellfish biodeposits and consumption by shellfish of some fraction of the natural planktonic grazer community.
- *Nutrients concentrations*. There is ample evidence to link shellfish aquaculture as a major control on coastal nutrient dynamics. However, the use of nutrients as indicators of bivalve culture impacts is challenging owing to the high natural short- to long-term variability of nutrient concentrations in coastal systems. Changes in different nutrient ratios may be more informative and other pelagic indicators (e.g. phytoplankton abundance, productivity and turnover time) may act as suitable proxies for detecting impacts on nutrient dynamics.
- *Dissolved oxygen (DO)* measurements are relevant to a wide range of aquaculture/ecosystem interactions and are therefore potential indicators of ecosystem status.

4.4.1.4 Shellfish performance indicators

Shellfish performance indicators include *growth rate, condition index, and meat yield per husbandry effort*. These measures share a similar property with bulk particle depletion measurements (above) in that they do not reveal information on specific changes in the structure and functioning of ecosystems, but provide an indication as to whether shellfish aquaculture is affecting the system to a greater extent than can be absorbed by natural processes. Particle depletion and shellfish performance measurements are highly complementary, as the former provides information on food supplies that likely control the latter. Monitoring condition indices is a way to assess how the physiological status of bivalve is affected by trophic availability into the environment. However, shellfish performance indicators are also affected by gametogenesis (the maturation of gametes) and should only be used if baseline (pre-culture) and reference data from unexploited environments are available.

Shellfish performance indicators have been measured on cultured and separately caged shellfish. A major strength of caging shellfish for this purpose is that standardization of shellfish performance measures is simplified. However, in the typical case of large spatial (horizontal and vertical) and temporal variability of environmental conditions (particulate food supplies) in the farmed region, the performance of the caged shellfish will be highly site-specific. Although the use of caged bivalves as indicators of ecological performance has potential, the interpretation of the results requires complementary information on a wide range of variables that can affect bivalve growth (temperature, currents, food abundance and nutritional quality, salinity, etc.), thereby decreasing the practicality of this approach (i.e. difficult interpretation by managers).

Time-series measurements of farm stocking and production have proven useful as indicators of growth conditions within extensively leased mussel aquaculture inlets (Cranford *et al.*, 2006). Long-term trends in total shellfish production (e.g. average

mussel and oyster yield per culture unit) have been used to assess the effects of increasing stocking density on bay-wide aquaculture production (Héral, Bacher *et al.*, 1989). These data are generally collected for aquaculture operations for purposes other than assessing aquaculture impacts and are both important for facilitating the interpretation other indicator results (e.g. phytoplankton depletion, benthic indicators) and as a general indicator for assessing bay-scale ecological performance/status.

4.4.1.5 Socio-economic indicators

An integrated, ecosystem-based shellfish aquaculture management approach requires endorsing socio-economic (impacts) activities as well as the environmental dimensions of sustainability. Indicators of socio-economic issues not only need to measure the operating performance of commercial fish farms, which at its simplest could be summarized using financial ratios, but also the wider impacts of aquaculture on society at large. Indeed, it is precisely these impacts which, within the DPSIR framework, that can be expected to invoke an institutional response intended to alter the way in which aquaculture is regulated and managed (from www.ecasa.org.uk). Among the many different indicators proposed in the literature, some are of direct relevance for shellfish culture operations. They are related to four different overarching social dimensions, namely (1) the social acceptability of the shellfish culture, (2) the supply availability to the market, (3) the livelihood security for the local communities, and (4) the economic efficiency of shellfish culture operations. Possible indicators (in italics) related to these four social dimensions are outlined below.

Social acceptability of the shellfish culture operations can be assessed with two indicators:

- *Public attitude towards aquaculture* (shellfish culture). This is evaluated by means of regular enquiries, using statistical treatments (Whitmarch and Wattage, 2006).
- *Assessment of emerging and existing conflicts*. Shellfish culture may be the origin of visual intrusion, which may impact tourism, or it may compete for space with other coastal activities in a spatially constrained environment. These can be evaluated by means of observations, regular interviews with local stakeholders and institutional bodies.

An indicator on the supply availability to the market corresponds to the consumption of shellfish products and to their entailing costs for the consumer:

- *The consumption of shellfish* is usually computed at national levels, indicating the quantity of food per capita and per year.
- *The consumers' price* is based on the trends in wholesale prices. Large national markets publish trade journals from which these data can be obtained.

Livelihood security for the local communities corresponds to the well-being of the shellfish producer on the local level. Indicators that address this issue pertain to:

- *Income per capita*. The importance of aquaculture in supporting local livelihoods is most directly measured by per capita income in this sector. A proxy measure may be derived based on the ratio gross value added (GVA) to employment.
- *Employment rate*. Total employment is a measure of the scale or 'importance' of the aquaculture industry in absolute terms. It is an indicator of the numbers of people who depend on aquaculture directly (and indi-

rectly) for their livelihood. It has a political as well as an economic significance.

One of the most important group of indicators relate to the direct economy efficiency of a particular shellfish aquaculture operation. These can be gauged as follows:

- *Productivity ratio.* Productivity is a measure of output per unit of input. For instance, trends in labour productivity are an important indicator of technical progress in aquaculture, and productivity differences between farms may indicate which farms are most vulnerable to falling prices and profits.
- *Protection costs.* Costs may be incurred in dealing with the environmental impact of aquaculture, and are likely to consist of two elements: (i) Compliance costs incurred by fish farms (e.g. arising from the obligation of farms to undertake EIAs) and (ii) regulation, surveillance and enforcement costs by the respective institutions. Environmental protection costs are the counterpart of environmental damage costs. Thus, an inverse relationship between these can be expected.
- *Profit.* Profitability is a basic indicator of financial viability. In the absence of published data, the profitability of a shellfish operation can be addressed and calculated from its different elements (i.e. input costs, pricing of products, etc.)

4.4.2 Scale issues of indicators

Over the past decades, scientists and policymakers have become increasingly aware of the complex and manifold linkages between ecological and human systems, which generated a strong research effort into social-ecological systems analysis. Social-ecological systems are understood to be complex adaptive systems where social and biophysical agents are interacting at multiple temporal and spatial scales (Janssen and Ostrom, 2006). This has stimulated researchers across multiple disciplines to look for new ways of understanding and responding to changes and drivers in both systems and their interactions (Zurek and Henrichs, 2007). Integrated coastal zone management (ICZM) and integrated shellfish cultivation can be viewed as being part of this social-ecological system paradigm, in which special emphasis is placed on the complexities of coastal settings and their manifold drivers in ecological and human systems.

By addressing the interactions and feedbacks between issues (e.g. economic, social and environmental consequences) it becomes evident that many of these play out over time (i.e. in past, present and future contexts) and space (i.e. at local, regional and ecosystem/global scale)—these are referred to as ‘cross-scale’ or ‘multi-scale’ processes. To take account of this array of complexity in the context of decision-making, a number of research supported approaches to indicator and monitoring systems have been developed and advanced to better understand the current and future interaction of various driving forces (Carpenter and Brock, 2006). Recently indicator systems have also been used to address multi-scale processes or to link social-ecological systems developed at various geographical scales with each other in order to better understand the interaction of processes, objectives and institutional arrangements across scales (Carpenter *et al.*, 2008).

Processes at different geographical scales, however, commonly unfold over different time-scales: the more aggregated the geographical scale (e.g. the regional ecosystem scale), the slower a system's dynamics unfold. Conversely, at a less aggregated geographical scale (e.g. the local scale) the social-ecological dynamics are more respon-

sive. Thus, in a hierarchical system, the more aggregated level can be seen to set the boundary conditions for any lower level of aggregation (Zurek and Henrichs, 2007). Thus, larger scales are required to understand the *context* in which an indicator works and the smaller scales support our understanding of the underlying *mechanisms* of the respective indicator. The level of interconnectedness across scales varies and depends largely on the approaches used to develop multi-scale indicators.

There are “fast” and “slow” variables that can be employed as indicators of the effects of shellfish aquaculture on marine ecosystems. Slow response variables are frequently important driving forces for dynamic interactions in an ecosystem (e.g. semi-enclosed estuaries with little tidal range vs. oceanic conditions), while fast variables describe component dynamics that iterate more rapidly (e.g. phytoplankton growth). Slow variables, such as currents and residence time in a water body, provide the context for the dynamic interactions of fast response variables of a system. Component relationships between these types of variables (i.e. between ocean currents, productivity and production output of shellfish) have to be integrated to capture intrinsic local-specific properties. A number of conditions and processes among the slow variables act as basic drivers of change. For instance, while ocean currents are not inevitably persistent, they certainly condition the initial direction of economic, social and environmental change and may strongly influence even the long-term future. However, unlike fast variables, the slow variables often are not easily manipulated for management purposes. For both types of variables, it must be emphasized to describe the relationship of all indicators to the functioning of the ecosystem and the type(s) of shellfish aquaculture operation.

As our frame of reference, we distinguish two levels of indicators across scales: (a) scale-dependent indicators that require a certain scale of perception to make them appear in a certain way and (b) scale-independent indicators which do not change their qualities when perceived on different scales. Which indicator is best suited and how much interconnectedness is needed, will depend on the focal issue and the primary purpose of the indicator, i.e. whether the aim is scientific exploration or decision-support for management (of shellfish aquaculture). The latter is more relevant to our objectives but cannot be decided by science/ICES alone because it is related to the respective social and policy arena of the ICES member states. The latter acts as the key denominator for the definition and local acceptance of thresholds for the respective indicator because it reflects the basic overarching logic of local/regional decision-making and their respective societal values. Thus, indicators need to be site-specific and measurable and relevant at local levels and political realities, in order to gain both local acceptance and to achieve practical application.

Commonly, indicators for shellfish cultivation are built around a set of driving forces and focus on processes at a specific geographic scale that shape the shellfish aquaculture development. This includes the locally-rooted decision-making context in which it operates, because the application of certain indicators and their respective thresholds for shellfish cultivation may differ between countries and between regions as a result of differences in needs, traditions, cultures or management systems. More recently, indicator approaches have also been used to address multi-scale processes and to link repercussions at various geographical scales with each other to understand more fully the cross-scale interactions of shellfish cultivation. For example, geochemical parameters indicating reductions in benthic communities inside mussel farms in Prince Edward Island, Canada, embayment's (Hargrave *et al.*, 2008, Cranford *et al.* in press) go hand-in-hand with observations of local and bay-scale phytoplankton depletion (Grant *et al.*, 2008), the attraction and increased productivity of some

demersal fish species, impacts of mussel biodeposition on ecosystem energy flow and nutrient cycling, and cumulative interactions between the benthic and pelagic effects of aquaculture and coastal eutrophication from land-use (Cranford *et al.*, 2007). This integrated, multi-scale approach allows, for example, specific decision units (be it an individual, a company, an organization or even a country) to think about implications of shellfish cultivation in a wider decision context. This context is usually outside the immediate sphere of influence of the decision unit itself, yet sets the boundary conditions and highlights the respective dependencies against which any decision needs to be taken.

In some instances it may be possible to manage small scale environmental conditions by managing aquaculture. However, as the scale of the area to be managed increases, so many other users and factors have to be considered that managing aquaculture alone is inadequate for managing environmental quality. In a multi-scale indicator concept, not all indicators on one subject are relevant to other subjects and to other scales. Therefore, one can distinguish between *intermediate indicators* and *end indicators* for a respective geographical and temporal scale. Figure 4.4.2.1 provides a schematic sketch on this distinction. Within the WGMASC, there had been a considerable effort to compile a list of relevant bio-geophysical indicators (see above). These cover a wide range of intermediate and end indicators on various levels, including a review on the relevant legislative and policy framework in the EU in which shellfish cultivation and the monitoring of key indicators may take place.

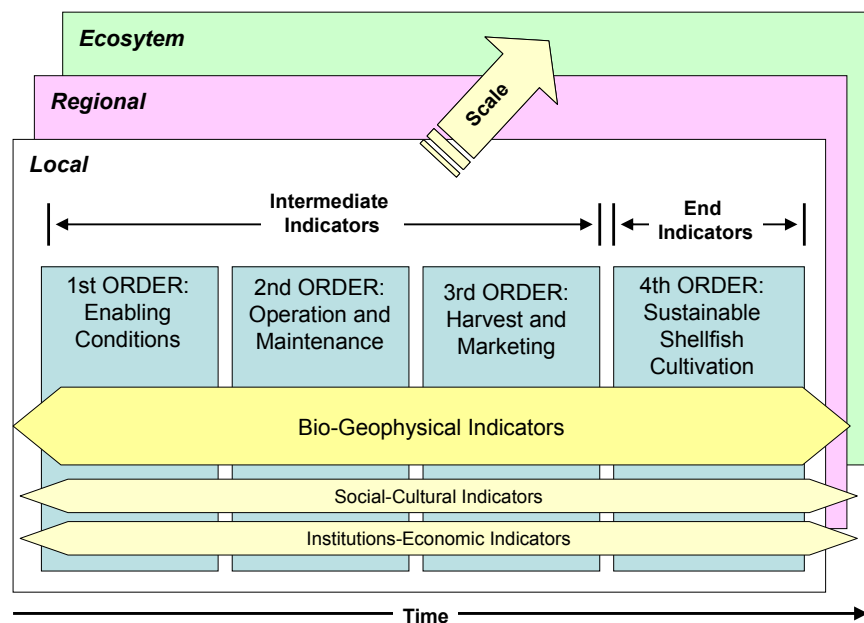


Figure 4.4.2.1. Schematic of the multi-scale indicator concept based on a natural science/shellfish operation point of view. A similar approach, with different indicators, may be established to focus on social science.

4.5 Management thresholds

“Threshold” is a general term of value that can be determined by administrative or scientific processes. For example, there are thresholds such as “no change in water colour as a result of eutrophication”. That is a threshold derived from policy imple-

mentation of a sense of what is socially acceptable. The scientific expression might be “no more or less than $1 \mu\text{g l}^{-1}$ of chlorophyll”. The threshold in this case is set by a policy statement. In contrast, if the desire is to prevent mortality of clams you might set a threshold defined by our scientific knowledge of the organisms’ response to environmental change. There are other less well-defined thresholds which determine the point at which ecosystems show a sudden regime shift from one state to another. For example, a trophic web based on microalgae is a highly productive system for bivalve culture. However, if that system suddenly shifted to a system based on picophytoplankton, it may have the same or more primary productivity but much of it would not be available to bivalves. In identifying a threshold it must be emphasized to be clear on whether the threshold is one determined by policy decisions or by changes in ecosystems.

It is difficult to set a threshold and sometimes the criterion is simply a “no net loss” or “no change”. (Un)fortunately, nature is not static. The environment is always changing. To set an adequate threshold, scientists, managers and all stakeholders must together identify the value of acceptable change from reference conditions. To address these difficulties, ecosystem managers increasingly use a monitoring endpoint, known as thresholds of potential concern (TPC), to decide when management intervention is needed (Biggs and Rogers, 2003). TPCs are a set of operational goals along a continuum of change in selected environmental indicators (Gillson and Duffin, 2007). TPCs are being continually adjusted in response to the emergence of new ecological information or changing management goals. They provide a conceptual tool that allows ecosystem managers to apply variability concepts in their management plans, by distinguishing normal “background” variability from unpredicted change or degradation (Gillson and Duffin, 2007).

The use of thresholds is often based on mean values but it has been shown in many studies that the ecosystem’s response to a disturbance is an increase in variability. It is possible to observe no change in the mean values of the indices, although the variability may increase through time, making it impossible to adequately select a threshold. However, setting thresholds based on means are often not enough. It is often the extremes that shift ecological status. The following is an example of how extreme conditions can have important ecological and aquaculture implications. The cockle (*Cerastoderma edule* L.) is the dominant species at the mouth of the Ulla River, located in the Ría de Arousa of Spain. Normally salinity conditions in the area support a thriving population of cockles (more than 500 T extracted worth approximately 2 million € per year). However, a prohibition of sand extraction from the river bed in recent years, together with tidal currents, dam controlled flow discharges in the river and strong winter winds has created new intertidal sandbanks. These sandbanks modify the mixing of fresh and seawaters in the area. Occasionally, this new configuration of sandbanks leads to a reduction of salinity in cockle beds (below 10 ppm) for period of 24 h or more. That reduction in salinity results in the death of an important part of the cockle stock. So, while on average the conditions in Ulla River mouth would normally favour cockle growth the occasional dip in salinities make the area no longer suitable for cockle rearing.

In the case of large areas of shellfish cultivation it is not always possible to set thresholds as there is considerable spatial variability of the natural spatial distribution of water quality parameters. Consequently when thresholds are set it must be emphasized to determine the sampling design criteria that must be used to determine if a threshold has been passed. A change can always be detected whatever the disturbance is, and its detection will only depend on the sampling effort. Inversely, it is

easy to detect no change, deliberately, by using a sampling design with low statistical power. There is a need to consider how regional and operational differences impact the applicability of indices and thresholds for assessing shellfish aquaculture ecological effects. Some examples of considerations in deriving the design of sampling methodologies include:

- geographic and topographic location (e.g. Rias, Fjords, Wadden Sea),
- seasonal and spatial variation in an indicator,
- effect size that needs to be detected while preventing type I and II statistical errors,
- the intensity of culture relative to the area and/or volume of the embayment,
- the rate of depletion of phytoplankton within bays, estuaries or the open ocean (e.g. different exchange/mixing of water body and influx from tidal backwaters or other productive areas),
- the rate of deposition of faeces in high energy environments or water bodies with low currents (e.g. Fjords ↔ open ocean)
- the rate of oxygen depletion within the water column (e.g. low mixing of water and high production of organic matter)

Instead of partitioning the range of variation of an indicator into 2 classes (acceptable vs. unacceptable), a few more threshold classes / categories may be more pertinent in specific cases (like in the case of European microbiological zonation based on different concentrations of *E. coli*). Such a system, based on sediment geochemical classification, is currently employed in parts of eastern Canada to manage benthic effects from aquaculture. This responsive management framework is designed to avoid harmful alterations, disruptions and destruction of marine habitat. A series of operational thresholds are defined by total free sulphide (S) and redox potential (Eh) in sediment collected at aquaculture sites. Progressively more rigorous monitoring and management requirements are automatically implemented in response to degrading site classification, based on predefined benchmarks. Monitoring and site management responses are used to delineate the temporal and spatial extent of the effect and promote oxic benthic sediment conditions. The basis for the above Canadian aquaculture (finfish and shellfish) management framework is the common quantitative scale for defining organic enrichment effects given in Hargrave *et al.* (2008). That study showed how all sediment and benthic community indicators of organic enrichment (see Sections 4.1.1 and 4.1.2) are linked along a continuum with enrichment zones that can be classified based on "sulphide regimes" (Figure 4.5.1). Consequently, these operational thresholds and the related aquaculture management approach are firmly rooted in science.

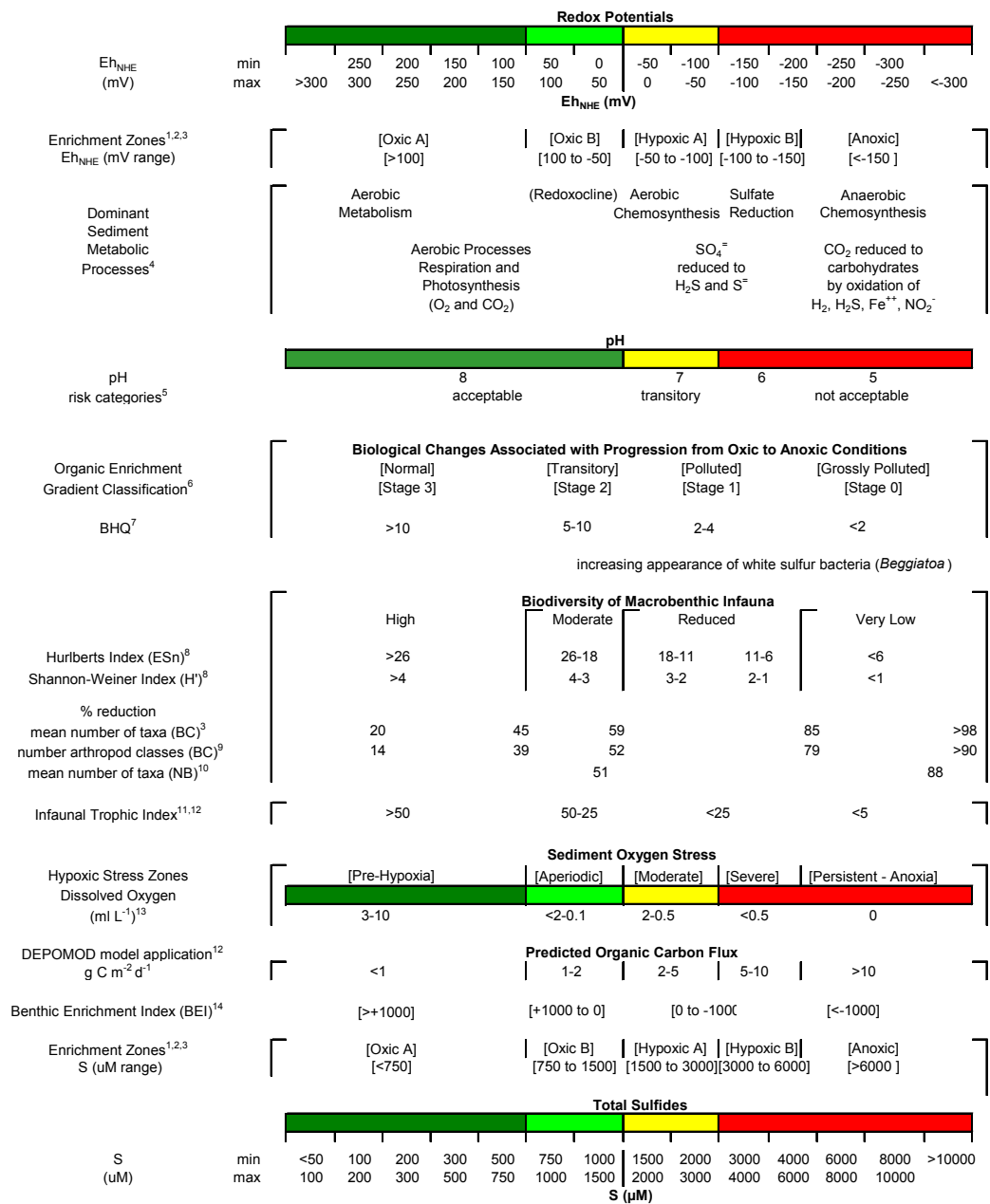


Figure 4.5.1. The Hargrave nomogram showing relationships between total S²⁻ and other indicators of organic enrichment in marine sediments from Hargrave *et al.* (2008). The coloured bars represent enrichment zone classifications for total S²⁻, Eh_{NHE} and pH that are separated by threshold values that can be used in managing aquaculture impacts.

4.6 Recommended Performance-based Management Framework

4.6.1 Assessment of indicators

Not one universal set of indicators is applicable in all cases (Segnestam, *op.cit.*). However a small set of well-chosen indicators tends to be the favourite choice of most users, including the stakeholders for aquaculture. A number of selection criteria can be applied when there is a need to constrain the number of indicators. Several recent papers have proposed a list of performance criteria for environmental or ecological

indicators (Kurtz, Jackson *et al.*, 2001, Rice, 2007) and specifically for fishery indicators (Garcia and Staples 2000) and shellfish aquaculture (Cranford *et al.*, 2006, Gibbs, 2007). Rationale is presented in the following sections for the presentation of indicators based on the following criteria:

- 1) *Relevance*: The meaning of an indicator represents the first essential phase in the process of indicator selection. The indicator selection must be closely linked to the environmental problems being addressed.
- 2) *Effectiveness*: This criteria is defined as the ability to respond to variations in aquaculture forces and pressures. While some indicators may respond to dramatic changes in the system, a suitable indicator displays high sensitivity to particular and, perhaps, subtle stress, thereby serving as an early indicator of reduced system integrity.
- 3) *Precision/Accuracy*: An indicator is considered to be robust if results are not too variable with regard to random (e.g. between-individual responses) or pseudo-random (e.g. hydro-climatic factors) fluctuations.
- 4) *Feasibility*: Theoretical indicator constructions are useless on an operational basis if adequate data are not available, either as a result of the fact that the data are technically very difficult to obtain or if collecting the necessary information is too expensive. Pragmatic considerations are paramount for identifying monitoring requirements for an industry that includes many small-scale operations. Low-cost measures of operational impacts are obviously preferable if they are able to contribute to the conservation and protection of fish habitat as effectively as more costly approaches. Indicators must be practical and realistic, and their cost of collection and development therefore needs to be considered. This may lead to trade-offs between the information content of various indicators and the cost of collecting them.
- 5) *Sensitivity*: A good indicator is expected to be both sensitive and precise. Ideally, the indicator has a known substantial response to disturbances, or anthropogenic stresses, and changes over time, and has low variability of response. This is most important for ecological indicators that address the complexity of ecosystems.
- 6) *Clarity*: Clarity is a pragmatic element of indicator selection. The ease of data interpretation is an important consideration for managers and non-scientists. The final uses of indicators are those of communication tools. Their significance should easily be understood by stakeholders. According to this criterion, the layman should retain the simplest concept and/or presentation for a better comprehension.
- 7) *Responsive*: For habitat/environmental management to be effective, the time frame between data collection and the decision-making process needs to be as short as possible. Responsive and adaptive management approaches strive to implement mitigation measures quickly so that the marine habitat does not continue to deteriorate. Near real time indicators therefore have a distinct advantage in such programs, whereas indicators that require considerable work to process samples and interpret data may be less desirable. Time lags greater than six months for scientists and managers to receive final results for an indicator can be considered undesirable.

4.6.2 Monitoring

A critical requirement an overall EBM framework is the availability of recommended methodologies and approaches for evaluating environmental status and shellfish aquaculture impacts. The EU Marine Strategy Framework Directive requires member states to develop programs to measure and maintain environmental status. Evaluation of impacts specific to shellfish aquaculture presents a challenge owing to the wide range of culture species, husbandry practices, and environmental settings, and variable spatial scale. Shellfish aquaculture farms may range from less than 0.5 hectares to operations in some regions that include a large fraction of total coastal embayment volume. Given the highly diverse nature of the shellfish aquaculture industry, it is not sufficient to simply provide a toolbox of potential indicators of environmental status specific to shellfish aquaculture, it is equally important to make recommendations, based on sound science, as to which tools are most appropriate under different conditions.

Aquaculture impact monitoring programs need to incorporate a high degree of flexibility to manage this diverse industry. It is therefore recommended that habitat assessments be based on a tiered monitoring approach that is structured on the principle that *increased environmental risk requires an increase in monitoring effort*. Various levels of monitoring could be triggered based on:

- the nature of the operation (e.g. species, culture method, proximity to other farms and stocking density per area or volume);
- the environmental risk predicted during aquaculture site assessments (e.g. ecological risk assessments and model-based predictions);
- the ongoing measurement of environmental indicators towards verification of operational thresholds; and
- other environmental sensitivity indices (e.g. presence of valued ecosystem components and sensitivity designations).

Inherent within this recommended monitoring framework is the basic principle that ongoing monitoring programs be continually adaptive to changes in our state-of-knowledge concerning potential environmental impacts and indicators, and related methodological approaches. It is important to maintain an ability to add or remove indicators to monitoring programs based on the evolution of our state-of-knowledge. Under the recommended responsive management framework, regulators would have the ability to increase or decrease the level of monitoring required for any site during subsequent sampling cycles, based, at least in part, on the review of all monitoring program results.

Aquaculture monitoring has generally focused on the benthic marine habitat in the immediate vicinity of a farm. This stems from the fact that the seabed habitat and species composition reflects the synergistic effects of past and present activities as well as natural processes that assimilate or disperse particulate wastes. There is also a relatively high level of understanding of benthic organic enrichment effects that has resulted in identification of effective indicators and scientifically defensible environmental targets (thresholds) needed to define the hypotheses that need to be addressed in an operational monitoring program. Effective measures are also available for mitigating benthic organic enrichment impacts, and these can be linked to operational thresholds incorporated in a responsive management framework.

Local benthic geochemical and community parameters, while useful for site-specific environmental monitoring, are of limited value as indicators of changes at the ecosys-

tem level. The pelagic and ecosystem level effects of dense shellfish populations cannot be predicted using benthic indicator observations at single sites. Some combination of modelling and measurement of selected far-field indicators related to underwater light properties, benthic and pelagic communities, suspended particle depletion, and perhaps shellfish performance, is needed over relatively large (inlet-scale) areas to adequately assess the effects of shellfish aquaculture on fish habitat and the ecosystem. Information on the number and sizes of shellfish leases and stocking information for all farms within the management area are believed to be essential to coastal ecosystem-based assessments of shellfish aquaculture impacts on fish habitat.

The inability to adequately define quantitative operational thresholds for many valid and highly relevant indicators of habitat and ecosystem status (particularly those describing the structure and dynamics of the water column), owing to present gaps in our knowledge of ecosystems, should not preclude their potential use. Surveillance sampling programs based on selected water column parameters and shellfish performance indicators are recommended under conditions where environmental impact assessments and ongoing monitoring data indicate a relatively high risk of bay-scale impacts. Of particular concern are potential impacts on suspended particle concentrations and distribution and the resulting alterations in pelagic microflora and fauna communities and the pelagic foodweb. Surveillance monitoring of a suite of ecosystem traits that are thought to affect productivity, community structure and habitat (i.e. contextual indicators; Gavaris *et al.*, 2005), is highly warranted when and where significant particle depletion by shellfish aquaculture is predicted. Seston depletion modelling capabilities have rapidly progressed in recent years and include some relatively simple quantitative assessment approaches and decision support systems. Surveillance of pelagic indicators would compliment benthic operational monitoring and would support the basic monitoring principle of delineating cause-effect relationships.

The following section provides specifics of the recommended tiered monitoring framework tailored to shellfish aquaculture and attempts to account for observed regional and species-specific differences in the environmental risks and impacts. The different monitoring tiers progress from the use of low-cost, semi-quantitative indicators, to more intensive monitoring and surveillance programs. The scientific rationale for selecting the appropriate level of monitoring is also provided. Discussions on the potential applicability of each of the wide range of aquaculture impact indicators identified above (Section 4.1) will be based on literature recommendations. Criteria for selecting indicators have also been provided above (Section 6.1) for the objective selection of indicators that are specific to specific operational needs. Examples of the potential components of the tiered monitoring approach are presented solely as a means of illustrating the concept of the tiered approach. The scientific rationale for selecting the appropriate level of monitoring is also provided.

4.6.2.1 Recommended tiered monitoring approach

For shellfish aquaculture leases that have been assessed as having a relatively low risk to impact fish habitat, only a minimal level of monitoring appears to be warranted. The **Level 1** monitoring program is intended to be a rapid screening method for periodic evaluations of shellfish aquaculture impacts at a given site. Examples of low cost, rapid screening indicators appropriate to Level 1 monitoring include the collection of benthic images (still photographs and/or video) and Secchi disk (light penetration) measurements, either annually or semi-annually at lease and suitable

reference sites (Table 4.6.2.1.1). The choice of reference sites for comparison with lease data would include consideration of general bathymetric, hydrographic and seabed type conditions in both areas. Prior to implementing a Level 1 program at a site, it is recommended that more extensive baseline data on environmental status be collected to ensure that benthic conditions are classified as Oxidic (Figure 4.5.1).

Table 4.6.2.1.1. Examples of habitat impact indicators appropriate to use in a tiered monitoring approach for shellfish aquaculture.

INDICATORS	MONITORING TIERS		
	Level 1	Level 2	Level 3
Benthic habitat			
Video	✓	✓	✓
Total S		✓	✓
EhNHE		✓	✓
Organic content		✓	✓
Benthic community			✓
Pelagic habitat			
Secchi depth	✓	✓	✓
Picoplankton contribution		✓	✓
Chlorophyll depletion area			✓
Stocking density/biomass			✓

Benthic video provides a qualitative or semi-quantitative assessment of organic enrichment impacts from shellfish biodeposits, while surveillance monitoring of Secchi depth may provide insight into long-term temporal trends in water clarity related to stocking density and large-scale particle depletion from shellfish feeding. The primary operational threshold that could be addressed in Level 1 monitoring is the appearance of white mats of bacteria on the seabed, that are indicative of a relatively high degree of organic enrichment and a potentially Hypoxic/Anoxic classification (Figure 4.5.1). A change in sediment type or a colour change from tan/brown to black during the monitoring program would provide early warning of increasing organic enrichment impacts that may be used by regulators to recommend additional monitoring to more accurately document the impact or to recommend mitigations. For small, mature, low-risk shellfish leases, where Level 1 monitoring has shown no habitat changes, a decision by regulators to cease or reduce the frequency of monitoring may be scientifically warranted.

A second monitoring tier (**Level 2**) is recommended to provide annual sediment geochemistry data in cases where there are indications (predictions) or previous measurements of organically enriched seabed conditions are deleterious to marine organisms. Possible indicator recommendations for Level 2 monitoring programs include bottom imaging and Secchi disk depths as described for the Level 1 program. In addition, the collection of sediment cores or grabs and water samples is recommended. Surface (2-cm depth) sediment could be analysed for redox, total sulphides, organic content and water content to indicate the degree of organic enrichment. Sampling would be best conducted annually in late summer/early fall when the biological oxygen demand of surface sediments is greatest. Water sampling would target

changes in the distribution and/or size structure of the phytoplankton (% picophytoplankton contribution), an indicator of ecological stability. The picophytoplankton contribution is generally less than 25% of total phytoplankton biomass (chlorophyll *a*), but is known to increase dramatically in areas of severe phytoplankton depletion caused by intensive shellfish culture operations. This relatively low cost measurement (size fractioned chlorophyll *a*) can be used to assess possible far-field effects on the phytoplankton and density-dependant effects on shellfish growth (ecological feedback). An annual shellfish inventory report for the lease would aid in interpreting results from this Level 2 program, as it would for all types of monitoring.

The third monitoring tier (**Level 3**) is recommended for assessing sites that are predicted to present a relatively high environmental risk and/or the results of ongoing Level 2 monitoring at the site show degrading habitat status (benthic performance thresholds exceeded). In addition to conducting all components of the Level 2 program (Table 4.6.2.1.1), the annual collection of other habitat data are recommended, including:

- benthic community analysis;
- spatial delineation of the magnitude and spatial extent of pelagic particle depletion (e.g. chlorophyll); and
- characterization of bivalve performance indices within each lease.

Sampling should also be increased to give greater spatial detail, depending on the monitoring plan developed by the regulator, on a site-specific basis. As with the other monitoring tiers, it is recommended that regulators have the capacity to alter the level of monitoring required for any site during subsequent sampling cycles, based on the review of the Level 3 program results.

4.7 EBM, International Regulatory Policies and Shellfish Culture

Current ecosystem management frameworks in place at national and international levels reflect the wide range of interests and goals that exist. Strong efforts have been made recently in the field of recognizing public goals, values and thresholds and being explainable and implementable in a consistent way to different people and groups. The new EU directive on establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive) is a case in point. The conclusion is that a parallel, linked system of substantive and procedural goals that are defined by a specific set of indicators at different levels of complexity and for different disciplines is needed to facilitate effective ecosystem-based management. However, at a microlevel most planners and managers of both ecosystems and economies, such as shellfish aquaculture, continue to pursue traditional goals and targets that may miss many desirable characteristics of ecosystem-based management goals targeted by national legislation. The problem is that specific thresholds of indicators may change according to the respective location or production site, region or type of ecosystem. So far, the link to build on existing administrative institutions is far from being complete, because these pertain to a wide range of different objectives within the DPSIR framework (Figure 4.7.1). The general tendencies of the respective frameworks reveal the different embedded perspectives of the EBM approach. The EU legislations having the most influence on shellfish aquaculture pertain to a large extent on the assessment of the state and impact of the environment (Figure 4.7.1; blue shading), followed by possible solution pathways (green shading). Only a few legislations focus mainly on the causes of the problems and suggest potential responses to these (red shading).

To date in Europe, most legislative and policy frameworks relevant to shellfish aquaculture revolve strongly around assessment of the state of the environment and specific anthropogenic impacts (Table 4.7.1). Institutional arrangements that ensure adaptable, flexible and iterative processes of applying a suite of tiered indicators that would support decision-making and management of shellfish aquaculture are only recently appearing. The scope for streamlining shellfish aquaculture throughout the EU has increased by the introduction of the Maritime Policy and by the link of terrestrial/coastal activities (as stipulated by the Water Framework Directive). In both cases, an ecosystems-based management approach is either already in place or planned to be formed. During recent years the EU has made significant progress in devising policies with respect to encouraging the integration of sectors and the involvement of stakeholders and the wider public. As a case in point, the EU Cohesion policy aims to synergize economic and environmental concerns, especially taking local social-economic issues into account.

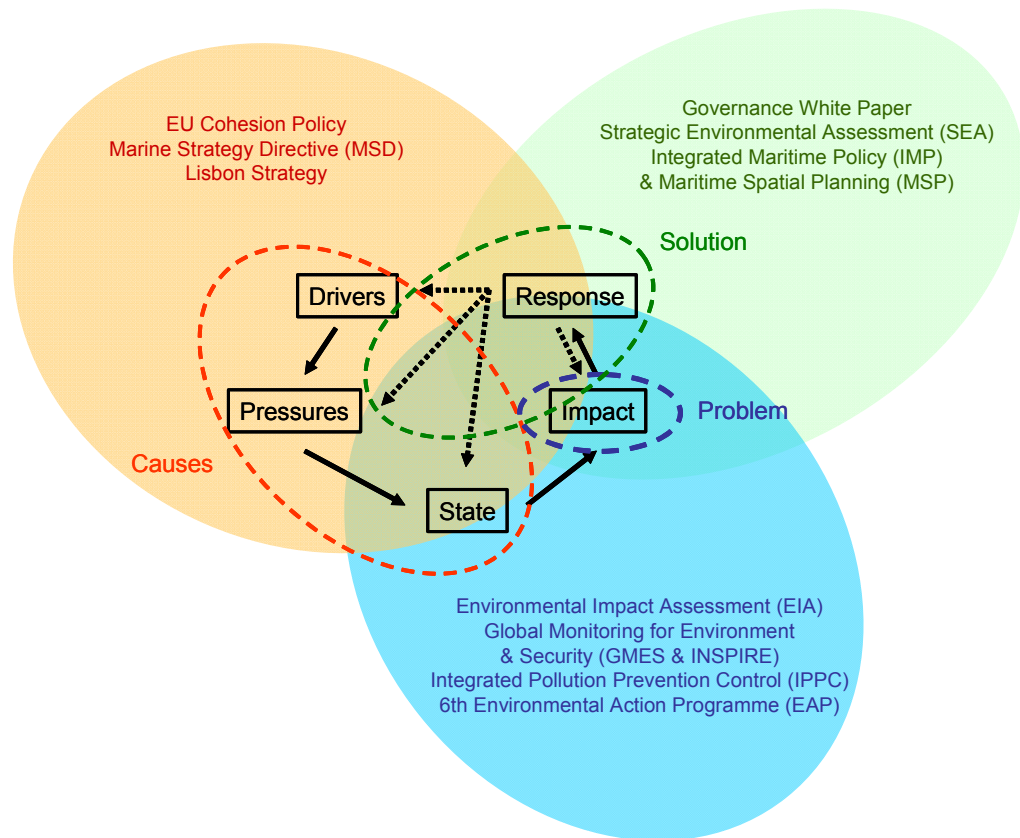


Figure 4.71. Clustering of the different EU frameworks within the DPSIR scheme.

Table 4.7.1. Selected legal and policy frameworks in the EU that employ, at least in part, an ecosystem-based approach (EBM) and which are important to shellfish aquaculture. These frameworks can be viewed as a vehicle to recognize and address critical issues and minimize conflicts pertaining to shellfish aquaculture. Scope for added-value of these frameworks for shellfish aquaculture is listed and their relative magnitude of impact is estimated, ranging from low (one dot) to medium (two dots) and high (three dots) impact.

Legal Frameworks on EU Level			
Framework	Major Contents	Relevance to Shellfish Cultivation	Magnitude of Impact
Marine Strategy Framework Directive (MSD)	<ul style="list-style-type: none"> • Knowledge-based EBM approach for decision-making • defines indicators for good environmental health status • defines clear monitoring and measurement programmes 	<ul style="list-style-type: none"> • sets guidelines and standards at national and regional level 	●●●
Strategic Environmental Assessment Directive (SEA)	<ul style="list-style-type: none"> • identifies environmental consequences of plans and programmes • considers transboundary effects • more transparent planning by public involvement and integrating environmental considerations. 	<ul style="list-style-type: none"> • Provides basis for integrated spatial planning and risk management • creates synergies by e.g. multifunctional use of marine space • addresses conflicts in long-term perspective 	●●●
Environmental Impact Assessment Directive (EIA)	<ul style="list-style-type: none"> • identifies and assesses environmental consequences of projects • strengthens the ecological component and defines ecological compensation measures 	<ul style="list-style-type: none"> • essential prerequisite of participatory EBM approach based on the precautionary principle • environmental damage as priority is rectified at source; inclusion of polluter-should-pay principle 	●●●
Industrial Installations and the Integrated Pollution Prevention and Control Directive (IPPC)	<ul style="list-style-type: none"> • requires industrial and agricultural activities with a high pollution potential to have a permit • issue of permit only if certain environmental conditions are met • public opinion must be taken into account in licensing procedure. 	<ul style="list-style-type: none"> • affects and protects aquaculture and fishery even beyond coastal waters • endorses quality required of shellfish waters 	●●●
Global Monitoring for Environment and Security (GMES) and Spatial Information in the Community (INSPIRE)	<ul style="list-style-type: none"> • streamlines European activities and funds in the field of Earth observation • pools and integrates data obtained from a variety of sources and presents them in a user-friendly format • aims to establish common platform for annotating and sharing geographic data 	<ul style="list-style-type: none"> • essential element for establishing an appropriate marine data and information infrastructure • provides valuable data and information for shellfish producers via monitoring of activities at sea ("maritime surveillance") 	●●

Policy Frameworks on EU Level			Magnitude of Impact
Framework	Major Content	Relevance to Shellfish Cultivation	
The Lisbon Strategy	<ul style="list-style-type: none"> aims to improve European economic development and the labour market situation, focusing also on environmental aspects protecting nature and combining economic and ecological aspects are key issues 	<ul style="list-style-type: none"> protection of the environment that also comprises the economic use of the coast supports alternative livelihoods in rural peripheral coastal regions generated by aquaculture 	●
Governance White Paper	<ul style="list-style-type: none"> policy-making process opened to stronger public participation promotes accountability and responsibility for parties involved stimulates greater use of different policy tools (regulations, "framework directives", co-regulatory mechanisms) 	<ul style="list-style-type: none"> integrates policies and regulations between countries and thematic areas (e.g. sectors), at national and European levels reinforces transparent mode of decision-making and management along European coasts 	●
EU Cohesion Policy	<ul style="list-style-type: none"> aims to redistribute wealth between richer and poorer regions in Europe via territorial cross-border cooperation balances economic integration and overall sustainable development in convergence regions achieves synergy effects in spatial planning 	<ul style="list-style-type: none"> supports rural peripheral areas where investments in infrastructure are in demand to employ shellfish aquaculture asks to comply with environmental legislation in the fields of water, waste, air and nature implements subsidiary and partnership principles useful for developing win-win situations in coastal areas 	●●
Integrated Maritime Policy (IMP) and Maritime Spatial Planning (MSP)	<ul style="list-style-type: none"> helps public authorities and stakeholders to coordinate their action optimizes the use of marine space to benefit economic development and the marine environment links the Integrated Maritime Policy, the Marine Strategy Directive and the Water Framework Directive identifies four environmental areas for priority actions, also considering economic and social aspects aims, among others, at better resource efficiency and improved resource and waste management, to stimulate more sustainable patterns of production and consumption 	<ul style="list-style-type: none"> offers opportunities to promote a continuum of integrated planning and management of aquaculture. promotes rational use of the sea and improves decision-making by balancing sectoral interests 	●●●
Sixth EU Environmental Action Programme		<ul style="list-style-type: none"> provides opportunity to bring aquaculture operations into wider context; from local, regional to national 	●

4.8 Summary

An integrated ecosystem approach to aquaculture (EAA) management has been defined as a strategy for the integration of aquaculture within the wider ecosystem in such a way that it promotes sustainable development, equity, and resilience of inter-linked social and ecological systems. A global activity related to the development of an EAA is the creation of performance-based standards that are linked to certification schemes and management frameworks designed to minimize the key social and environmental issues associated with shellfish farming while permitting the industry to remain economically viable. A recurring bottleneck to the establishment of an EAA is the need to define an “unacceptable” impact. This decision needs to be made within an integrated framework that is both science- and ecosystem-based, but which also incorporates societal values. The DPSIR (Driving Forces-Pressures-State-Impacts-Responses) framework is recommended as the basis for an EAA as it identifies environmental problems, their causes and solutions, and recognizes important linkages between ecological and socio-economic systems. DPSIR provides the means to structure sets of indicators in a manner that facilitates their interpretation, can aid an understanding of how different issues are interrelated, and is recommended as a basis for the assessment, evaluation and operational management of the impacts of shellfish aquaculture activities in the coastal zone.

A large suite of potential ecological indicators were reviewed that communicate information about ecosystem status and the impact that aquaculture activities may have on ecosystems to responsible authorities and to the public. Evaluation of impacts specific to shellfish aquaculture presents a challenge owing to the wide range of culture species, husbandry practices, and environmental settings, and variable spatial scale. Indicator selection criteria were provided to facilitate constraining the number of indicators within a flexible performance-based management framework. A variety of modelling activities are contributing to the movement from reactive to proactive aquaculture management. Modelling facilitates an understanding of how all culture units interact over a scale relevant to coastal ecosystems and are useful within the DPSIR framework to identify indicators of ecosystem status and aquaculture impacts, and contribute to the establishment of impact thresholds (regulatory triggers).

It is recommended that EAA be based on a tiered environmental monitoring approach that is structured on the principle that increased environmental risk requires an increase in monitoring effort. Aquaculture monitoring has generally focused on the benthic marine habitat in the immediate vicinity of a farm. However, local benthic geochemical and community parameters, while useful for site-specific environmental monitoring, are of limited value as indicators of changes at the ecosystem level. Some combination of modelling and measurement of selected far-field indicators related to benthic and pelagic communities, suspended particle depletion, shellfish performance is needed over relatively large (inlet-scale) areas to adequately assess the ecosystem-level impacts of shellfish culture. It is recommended that regulatory decisions be based on partitioning the range of variation of an indicator into more than two classes/categories (acceptable vs. unacceptable). A few more threshold classes permits implementation of mitigation measures prior to reaching an unacceptable ecological state.

The recommended EAA framework, which is linked to the DPSIR scheme, was assessed relative to the focus of EU legislations and policy frameworks. Most legislative and policy frameworks relevant to shellfish aquaculture revolve strongly around assessment of the state of the environment and aquaculture impacts. The introduction

of the Marine Strategy and Water Framework Directives (also Canadian Oceans Act) mandates a DPSIR-type EAA approach that links ecological and socio-economic systems. It is therefore essential that the development of a management framework should be inclusive with diverse stakeholder participation, transparency and communication.

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

5.1 Background

Movement of shellfish around the world is an activity that has a long history (Wolff and 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 and Seed 1991; Calvo-Ugarteburu and McQuaid 1998; Camacho *et al.*, 1997; Desclaux *et al.*, 2004; Dethlefsen 1975; Taskinen 1998; Tiews 1988; Wegeberg and Jensen 1999; Wegeberg and Jensen 2003).

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 summarized below.

5.2 Related reports of WGITMO and WGEIM

5.2.1 2007 of the WGITMO¹

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 non-sterile triploids, can be considered (including an environmental impact statement with alternatives, scientific contributions in support of the EIS, and a review concerning the utility of ICES Code of Practice guidelines in the current process). This deliberate introduction offered an opportunity to evaluate: how well the Code of Practice (ICES) is being followed; the Code’s strengths and weaknesses, and what can be said about the risks involved in the process that the US adopted.

5.2.2 2008 of the WGITMO

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

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

non-indigenous species. This supports the hypothesis that the species have been inadvertently 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 of the WGITMO (draft version)

The 2009 WGITMO report contains an alien species alert on *Crassostrea gigas* as an annex. One of the chapters in this alert concerns the worldwide introduction of *C. gigas* for aquaculture purposes and a chapter on the consequences of this introduction.

At the end of the report in Annex 1 there is a table including non-native species identified as considered problematic. Some of the listed species were transferred or introduced by shellfish originating in aquaculture.

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 3² 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.

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”.

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 consulta-

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

tion 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 ToR f) (formerly 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 as a result of 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 c) and d) is on the significance of bivalve aquaculture transfers between sites (local, regional, national, 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. Because 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

Last year the role of WGMASC was defined; following the screening of the SGBOSV, WGIMTO and WGEIM reports and considering risks not covered by those terms of reference. In addition, current guidelines and records are to be reviewed together with a summary of shellfish movements not covered by those reports. In this second the collection and collation of data were continued and a start was made with listing potential effects and implications for wild shellfish stocks. In future years the ToR will be completed with a final report including recommendations on scientific tools for decision support and on shellfish transfers in general

5.5 Guidelines

5.5.1 Introduction

Aquaculture must compete for and share space with other interests such as fisheries (the public right to fish); anchorages, effluent discharges, sites of scientific interest, tourism etc. Legislation and industry codes of practice exist worldwide to control environmental impacts and diseases associated with transfers of molluscan shellfish species, both cultured and wild. These include: the ICES code of practice; OIE guidelines; natural heritage organizations (e.g. English Heritage and Scottish Natural Heritage in Britain) concerning conservation and sustainability of resources, and EU council directives related to both shellfish and human health, e.g. Directive 2006/113/EC of the European parliament and of the council of 12 December 2006, on the quality required of shellfish waters. In addition, in the absence of statute or CoPs, negotiation between industry and authority is often used at the local level to help protect the environment. A review of these guidelines is intended to show where and how controls are implemented and how these may be integrated and developed to minimize the risk of environmental influences including disease.

The United Nations Convention on Law of the Sea (UNCLOS) is an international agreement which defines the rights and responsibilities of nations in their use of the world's oceans, establishing guidelines for businesses, the environment, and the management of marine natural resources. To date 155 countries (including the European Community) have joined in the Convention. A management role is played by organizations such as the International Maritime Organization, the International Whaling Commission, and the International Seabed Authority

The international law of the sea includes the exploration and exploitation of the exclusive economic zones (EEZ) of all countries in which these countries are able to exploit (e.g. harvest) their resources (including aquaculture). The exploration and exploitation of the exclusive economic zones (EEZs) has become of major importance for maritime countries. The knowledge of sub-bottom potential requires innovative underwater tools for optimization of research and exploitation. Technologies used are, in the main, drawn from different fields such as: imagery, bathymetry, marine seismic, current profiling, underwater positioning, magnetometry and sub-bottom analysis. EEZ exploitation requires the analysis of areas for industrial applications as well as scientific analysis. Seafloor analysis and mapping are of prime importance for fluid migration and margin structural analysis. One of the major steps in surveying is

the use of bathymetry and imagery analysis, which allows geologists to analyse the seabed structure. Bathymetric surveying is of great importance too, for cable and pipe laying (Denis, Jean-Francois Sea Technology, February, 2001).

Fish farming has an impact on the environment and that impact can be minimized by statute, consultation and good work practise. Most EU countries employ a complex aquaculture planning consultation process to minimize the environmental impact of developments and ensure the deposit and cultivation of aquaculture animals does not conflict with rights of others, e.g. an application for a farm lease in Scotland involves consultation with: Fisheries Research Services on the feasibility, environmental and disease implications of proposals; The Scottish Environmental protection Agency (SEPA) on discharge consents; Wild fishery interests by the Fisheries protection Agency and Fishermen's associations; potential conflicts of interest by local Harbour Authority, Scottish Pelagic Fishermen's Association, Scottish Anglers National Associations District Salmon Fisheries Boards and the Ministry of Defense; Scottish Natural Heritage who consider the ecosystem and aesthetic impact of an application; Health and Safety executive whose aim is to protect people against risks to health or safety arising out of work activities, and local press on public awareness, where seeking valid objections to a development. Local authority planning departments in Scotland coordinate the consultations process and decide its outcome, which is reported to the Scottish Government

If a lease is granted, the weight of statute helps set standards, e.g. Under the Environmental Impact Assessment (Fish Farming in Marine Waters) Regulations 1999. An application is likely to involve an environmental statement and an Environmental impact assessment (EIA). In addition industry codes of practice are designed to encourage sustainability with minimum impact, e.g. the Association of Scottish Shellfish Growers Code of Best Practice for shellfish aquaculture (<http://www.assg.co.uk/>).

Controls and Codes of Good Practice are reviewed below:

- European legislation
- International conventions regulating introduced species
- ICES Code of Practice
- National legislation
- Industry Codes of Practice
- OIE guidelines
- Natural Heritage Organisations
- English Heritage, Scottish National Heritage, Countryside Council for Wales
- Negotiation at local level

5.5.2 European legislation

With the adoption of the single European market in 1992, in order to promote trade among Member States, including that in live fish and shellfish, an EU Fish Health Regime was established to receive reports on any abnormal mortality in shellfish farm sites and limit the introduction and spread of the most serious diseases across Europe. This was based on Council Directives 91/67 EEC, 95/70/EC and subsequent Directives and Decisions, subsequently implemented by current fish health regulations. They listed controls that may be applied by member countries for certain diseases of shellfish, and established the concept of Approved Zones and Farms for

serious (list II) diseases (*Bonamia* and *Marteilia*), and introduced controls on movements to such Approved Zones and Farms, which were restricted to shellfish from sources of equivalent or higher health status. With EU agreement national programmes could then be established to prevent, control, contain or eradicate the disease. This legislation was replaced by directive 2006/88/EC, in the latter half of 2008; and implemented in Scotland by The Aquatic Animal health (Scotland) regulations 2009

5.5.2.1 Council Directive 91/67/EC

Movements of shellfish within the EU: The EU fish health regime requires that movements of molluscan shellfish susceptible to *Marteilia* and *Bonamia* are only made between zones or farms of equivalent health status and that movements of non-susceptible molluscs do not include sick or dead animals or carry the risk of transfer of these pathogens or hitch hiker species to approved zones or farms.

Criteria for listing diseases and current lists of specific shellfish diseases and susceptible species are listed in Annex IV Parts I & 2 of council Directive 2006/88/EC.

Consignments of susceptible shellfish species, for relaying or placing in depuration facilities prior to consumption into approved zones, must be accompanied by movement documents confirming the health status of the consignment. Each document must be signed by the Official Service in the region of origin and be drawn up at the place of origin within 48 hours prior to loading, in the language of place of destination, valid for 10 days of travel. All other species of molluscan shellfish must originate in *Marteilia* and *Bonamia* Approved Zones or Farms, or from other farms that do not hold species susceptible to *Marteilia* and *Bonamia* and which are not connected to any other water (using non susceptible species certificate as per 2003/390/EC, Annex 1, to be signed 24 hours prior to loading). *Crassostrea gigas*, *Mytilus edulis*, *Mytilus galloprovincialis*, *Ruditapes decussate* and *Ruditapes philippinarum* are recognized as not susceptible to or responsible for the transmission of *Bonamia*. *C gigas* was recognized as not susceptible to or responsible for the transmission of *Marteilia*. This certificate has a specific statement that at least 1000 molluscs must be inspected and no hitchhikers be seen and that they should show no signs of clinical disease on the day of loading. This certificate allows for *C. gigas* to originate in areas are infected with *Bonamia* and *Marteilia*. Certification is being updated in light of the new directive EC2006/88.

Inspectors must inspect and sign consignments prior to export, ensuring no clinical disease or the presence of hitch hiker species. If hitch hikers cannot be removed details must be provided on the certificate to prevent their introduction.

5.5.2.2 EC Directive 2006/88/EC

This directive on the animal health requirements for aquaculture animals came into force in 2008, when it replaced 91/67/EEC and 97/70EC. Amongst the significant changes to previous requirements, the new legislation adopts the following approach:

- a risk-based approach, notably for official surveillance for disease;
- requirement for "Aquaculture Production Businesses" to comply with conditions of authorization
- controls on movements of potential vector and non-susceptible species;

- a structure for declaring the health status of Member States and compartments, in addition to zones;
- the facility for Member States to self-declare disease freedom for zones and compartments

Specifically, APB's are required to:

- Keep a record of all movements of aquaculture animals and products, including dead fish
- Keep a record of mortalities occurring on the farm
- Participate in a risk based surveillance scheme and keep records of the results of any such scheme
- Implement and maintain good bio-security practices (referred to in the Directive as good hygiene practise).

Disease control: The Directive requires that competent authorities have measures in place that will prevent the introduction and control the spread of certain listed diseases. These diseases have been divided into two categories; exotic and Non-exotic. For bivalve molluscs the Exotic diseases are listed as: infection with *Bonamia exitiosa*, infection with *Perkinsus marinus* and infection with *Microcytos mackini*. The Non-Exotic diseases are listed as: infection with *Bonamia ostreae* and infection with *Marteilia refringens*.

Under 2006/88EC, under the draft certificate, all susceptible and vector species must be accompanied by a health certificate stating that each consignment be inspected on the day of loading. There is facility for the quarantine, controlling the movement of potential vector species, where these are considered to pose a risk to the health status of member nations.

5.5.2.3 The Water Framework Directive WFD (2000/60/EC)

The water Framework Directive (WFD) requires member states of the EU to characterize the pressures on river basin water bodies, by identifying the impact of ecological and chemical parameters on these aquatic ecosystems. The overall aim is to further improve European waters to meet the environmental objectives of the Directive. Specifically, the WFD requires that surface waters should meet "good ecological and chemical status" by 2015, ensuring in the meantime that no deterioration takes place. The Directive incorporates both chemical and environmental standards, which means that any activities that lead to biological changes, such as the introduction of alien species, must be taken into account during the risk assessment undertaken during the characterisation process.

Risk assessments for individual water bodies will need to evaluate the existence, or risk of introduction of alien shellfish species that have the potential to affect the environment. Among the species of interest in Europe that have been associated with aquaculture are: the slipper limpet *Crepidula fornicata*, which has been shown to be a hitch-hiker species carried with introductions of seed mussels; the Manila clam *Tapes philippinarum* and the Pacific oyster *Crassostrea gigas*, both species introduced to replace failing supplies of native species of shellfish. When assessing the impact of the introduction of these and similar species into new waters, the requirements of the Directive need to be taken into account in order to allow the establishment of an environmentally sound aquaculture industry.

5.5.2.4 Hygiene controls on movements of live bivalve molluscs

The European legislation on shellfish hygiene controls are summarized in Directives 852/2004EC and 853/2004EC. These require that transfers of shellfish between areas do not compromise the microbiological quality of either the source or destination. It will be necessary for other ICES member nation representatives to comment on their own countries policies as these views are not available at the present time.

5.5.3 International conventions regulating introduced species

The *United Nations Convention on the Law of the Sea* came into force in 1994. Article 196 on the use of technologies or introduction of alien or new species requires states to take all measures necessary to prevent, reduce and control "the intentional or accidental introduction of species, alien or new, to a particular part of the marine environment, which may cause significant and harmful changes thereto".

The 1992 *Convention on Biological Diversity* (CBD): "Each Contracting Party shall, as far as possible and as appropriate – prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species".

The 1995 *FAO Code of Conduct for Responsible Fisheries*: "9.2.2 States should, with due respect to their neighbouring States, and in accordance with international law, ensure responsible choice of species, siting and management of aquaculture activities which could affect transboundary aquatic ecosystems. 9.2.3 States should consult with their neighbouring States, as appropriate, before introducing non-indigenous species into transboundary aquatic ecosystems." ... "9.3.1 States should conserve genetic diversity and maintain integrity of aquatic communities and ecosystems by appropriate management. In particular, efforts should be undertaken to minimize the harmful effects of introducing non-native species or genetically altered stocks used for aquaculture including culture-based fisheries into waters, especially where there is a significant potential for the spread of such non-native species or genetically altered stocks into waters under the jurisdiction of other States as well as waters under the jurisdiction of the State of origin. States should, whenever possible, promote steps to minimize adverse genetic, disease and other effects of escaped farmed fish on wild stocks. 9.3.2 States should cooperate in the elaboration, adoption and implementation of international codes of practice and procedures for introductions and transfers of aquatic organisms. 9.3.3 States should, in order to minimize risks of disease transfer and other adverse effects on wild and cultured stocks, encourage adoption of appropriate practices in the genetic improvement of broodstocks, the introduction of non-native species, and in the production, sale and transport of eggs, larvae or fry, broodstock or other live materials. States should facilitate the preparation and implementation of appropriate national codes of practice and procedures to this effect."

The threat from introduced species was also emphasized in the *Plan of Implementation of the World Summit on Sustainable Development*, Johannesburg 2002, which called for actions at all levels to: "Strengthen national, regional and international efforts to control invasive alien species, which are one of the main causes of biodiversity loss, and encourage the development of effective work programme on invasive alien species at all levels".

5.5.4 ICES Code of Practice on the Introductions and Transfers of Marine Organisms

This document offers advice and best practice guidance on reducing the risk arising from the introduction of non-indigenous marine species, and includes sections dis-

cussing policies for ongoing introductions established as part of commercial practice. This guidance sets out a framework for evaluating the risks from such introductions, together with specific procedures for minimizing these risks. In doing this, the document repeats some of the requirements covered in the EU legislation and the OIE Aquatic Animal Health Code, as well as describing more detailed methods of inspection of consignments.

5.5.5 National Policy

5.5.3.1 Policy for bivalve transfers in the Netherlands

- 1) Transfer of bivalves into the Wadden Sea is not permitted, except for mussels from the Danish or German parts of the Wadden Sea.
- 2) To minimize the risks in the Eastern Scheldt, the following precautions are taken:
 - Molluscs from risk areas inside the boreal area (from the English Channel to the south of Norway and Sweden) may only be transported to the Eastern Scheldt, under licence. Mussel spat from the Dutch part of the Wadden Sea can be transferred to the Eastern Scheldt without permission.
 - It's not permitted to transfer molluscs from outside the boreal area into the Eastern Scheldt.
 - Processing water and tarra from outside the boreal area must be deputed before discharging it.

A new line of policy concerning the displacement of shellfish came into effect in 1997. Since then the transfer of mussels from the Irish and Celtic Sea into the Oosterschelde has not been permitted. Also the process effluent water and the tare from the consumption mussels originating outside the boreal waters needed to be purified before being discharged into the Oosterschelde (Snijdelaar *et al.*, 2004). In 2003, the Raad van State (Highest Court in the Netherlands) withdrew the ban for import on mussels from the Irish and Celtic Sea. It was brought forward that the ban was conflicting with the EC guidelines for freedom of trade. Also it was substantiated that the precaution principle was formulated as being too general (Snijdelaar *et al.*, 2004). From that period, the Dutch Ministry of Agriculture, Nature and Food Quality, issued permits for the displacement of mussels from the Irish and Celtic Sea into the Oosterschelde. However, the applicant had to prove that mussels originated from a particular production area in the Irish Sea, or have been in that production area for at least one year. In March 2006, the Raad van State decided that the existing permits were not valid. The Oosterschelde is part of the Natura 2000 network based on both the Bird (79/409/EEC) and the Habitat (92/43/EEC) directives. Any plan or project in the area likely to have a significant effect thereon shall be subject to an appropriate assessment of its implications for the site in view of the site's conservation objectives.

In the Netherlands, the production of mussels in the Wadden Sea and the Oosterschelde fluctuates as a result of varying recruitment and survival rates. Production does not meet the demand for mussels. To meet this demand, seed mussels and adult mussels are imported from other European countries. Wijsman and Smaal (2006) and Wijsman *et al.* (2007a, b) reviewed the risks of transport of mussels from Ireland, the UK, Sweden and Norway to the Dutch production areas. Based on the results of the study, a permit was given to the corporation of shellfish importers to import mussels and oysters from 12 production areas in Ireland and the UK into the Oosterschelde.

The imports of consumption mussels from these areas are monitored for the presence of exotic species by means of regular sampling upon arrival in Yerseke. Similar studies have been conducted by Wijsman *et al.* (2007a,b) on the risks in transporting mussels from Norway and Sweden to the Dutch Wadden Sea. At this time the corporation of shellfish importers are waiting for a permit for import of mussels and oysters from Norway and Sweden to the Dutch Wadden Sea.

5.5.3.2 Belgian policy

The user conditions as decided by the government of the four bivalve areas in the Belgian North Sea only permit the use of naturally settling spat, obtained by suspended cultivation methods. There are no guidelines for transfers between these areas. The concession owners have to report every notification of non-indigenous species, parasites or diseases to the Management Unit of the North Sea Mathematical Models. A small amount of oyster (both *C. gigas* and *O. edulis*) spat is imported every year for growout in the Spuikom in Ostend. These oysters are subjected to a veterinary control (Belgian law MB 97/16166).

A review of applicable legislation from other ICES countries will be included in later years.

5.5.3.3 Norwegian policy

According to the Aquaculture Act, transfer of biological material (in this case bivalve) between licensed sites should be approved by the Norwegian Food safety Authority. The approval is based on an evaluation of risk for disease transfer between salmonids and marine fish where the bivalves potentially can act as a vector.

Sea ranching of the scallop (*Pecten maximus*) licensed under the Aquaculture Act requires use of seeded scallops that originate in local stock. This implies that transfer of scallops between licenses for the purpose of producing seed for sea ranching can only be done when documentation is given on origin of broodstock in case of for intensive production of spat or area for natural collection of spat.

5.5.3.4 German policy

5.5.3.4.1 Blue mussels

Mussels cultivated in Germany are displaced on local, regional and international scale for both, export and import. Transfers are conducted with either seed and market sized mussels. Seed mussels are transferred by the fishers from their natural wild beds to the licensed cultivation plots. Usually the distances between these two locations are short and mussels remain in the same water body. Since mussels are fished obligatory from subtidal wild habitats and placed only subtidal culture plots a vertical transfer is likely to be minimized. Recently, spat cultivated on hanging cultures in the Jade estuary is transferred regionally to culture plots in regions at the North Frisian Islands. On international scale spat is imported from the UK and Denmark, owing to poor recruitment and failed spatfall in recent years within the German Bight.

Because seed mussels are placed at least for one season on the culture plots and not used directly for human consumption they are not subject to official hygienic control. Thus, all seed mussel imports are not monitored for their genetic homogeneity, microbial purity, viral or parasitic status, biotoxins or for the import of non-indigenous species either in their mantle cavity or on their shell. As a consequence of the lack of control no detailed data are currently available on amounts and their distribution to target sites from seed imports, despite the fact that cultivation is conducted within or

in the vicinity of the two National Parks of the German Wadden Sea (Lower Saxony Wadden Sea National Park, Schleswig-Holstein Wadden Sea National Park).

Market sized mussels are exclusively exported from Germany mainly to the Netherlands, France and Belgium. There, mussel are sometimes relayed e.g. in the Oosterschelde until they are sold on the market. Transfers of adult mussels from other places to Germany is unlikely at present, because the market for mussel products is saturated and current mussel price low. However, data on mussel exports and processing are not completely available, but are listed in the annual publications of the Federal Agency for Agriculture and Food (e.g. BLE 2001).

Transfers of mussels between the Baltic and the North Sea are neither conducted for seed nor for market sized mussels, but are planned by fishers in the near future. The plan is to collect mussels in the Baltic Sea then transfer them to the North Sea.

5.5.3.4.2 Oysters

The Pacific Oyster (*C. gigas*) is cultivated only at one farm in the tidal backwaters of the island of Sylt. The spat for this farm is imported from an Irish hatchery. As for blue mussel seed, these young oysters are not currently monitored by any official authority.

5.5.4 Discussion

There has been a move towards a more targeted, risk-based, assessment of movements of bivalve molluscs for relaying, that take place for commercial purposes. There is an understanding from legislators that such movements pose a potential for spread of serious disease, however the potential for environmental impacts other than disease is not currently addressed within the existing animal health legislation. This means that there may be occasions when implementation of the animal health legislation at a European level comes into conflict with ecological legislation at national level.

5.6 Records

5.6.1 Legislation

Record keeping requirements for shellfish businesses that existed under 91/67EEC and 95/70EEC are discussed below. It will be necessary for delegates from each ICES nation to comment on their own countries approach.

5.6.1.1 Record keeping requirements under existing fish and shellfish health legislation

Article 3 of 95/70/EC states that Member States shall ensure that all farms rearing bivalve molluscs:

- 1) are registered by the official service; this registration must be kept constantly up to date; and
- 2) keep a record of:
 - live bivalve molluscs entering the farm, containing all information relating to their delivery, their number or weight, their size and their origin;
 - bivalve molluscs leaving the farm for re-immersion, containing all information relating to their dispatch, their number or weight, their size and destination; and

- observed abnormal mortality.

This record, which shall be open to scrutiny by the official service at all times, on demand, shall be updated regularly and kept for four years.

Movements of shellfish from outside the EU are required to be accompanied by a suitable animal health certificate, signed by the competent authority.

5.6.1.2 Disease records

The Directive required that competent authorities have measures in place to prevent the introduction and control the spread of certain listed diseases. These diseases have been divided into two categories; exotic and non-exotic. For bivalve molluscs the exotic diseases are listed as: infection with *Bonamia exitiosa*, infection with *Perkinsus marinus* and infection with *Microcytos mackini*. The non-exotic diseases are listed as: infection with *Bonamia ostreae* and infection with *Marteilia refringens*.

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Movements of shellfish from outside the EU are required to be accompanied by a suitable animal health certificate, signed by the competent authority.

5.6.1.3 Requirements for record keeping under recently introduced legislation 2006/88/EC

This new Directive not only requires that aquaculture production businesses keep records of all movements of shellfish to and from their sites, but that these records be kept by shellfish businesses, including depuration plants and potentially by transporters and some processing plants. These records would include all movements of seed shellfish to shellfish farms, movements between farms and also movements from farms to the place of final processing. However, there is a provision in the regulations that would allow shellfish farmers who share the same mollusc farming areas to apply for a shared authorization. This reflects the spatial distribution of farms within hydrographic areas, and the effect of this on the potential spread of disease within these areas.

5.6.1.4 Record keeping under the EU Food Hygiene regulations

This legislation requires that each consignment of live bivalve molluscs is accompanied by a movement document which states the place and date of harvesting together with the details of the harvester. This is to allow full traceability in the event of a hu-

man health disease outbreak in the consumers of harvested shellfish. There are controls on the harvesting of shellfish, which cannot be taken from areas where there is no known microbiological classification, unless they are “seed” shellfish not destined for immediate consumption.

5.6.1.5 Movements of shellfish (what species are transported where?)

Movements of shellfish for aquaculture can broadly be divided into four categories:

- 1) movement of wild-caught seed for relay onto managed farms;
- 2) movement of hatchery cultured seed;
- 3) movement of farmed stock to other farms for ongrowing to final market size;
- 4) movements of farmed or wild stock relayed for depuration or at a dispatch centre prior to sale; and
- 5) movement of live shellfish to the final market (human consumption), which may be relayed at destination to improve condition.

Typical movements that take place within the aquaculture trade may include:

- native and Pacific oyster seed from hatcheries to nursery and ongrowing sites;
- part grown native and Pacific oysters from nursery sites to ongrowing sites;
- clam seed from hatcheries to ongrowing sites;
- scallops and queens from natural spat collection sites to ongrowing sites;
- mussels from natural seed beds to ongrowing sites; and
- shellfish relaid for depuration or held at a dispatch centre prior to sale;
- shellfish for human consumption which may be relayed at destination to improve condition.

These movements may take place either locally within shellfish harvesting areas, between shellfish harvesting areas within a region/country, between countries within economic regions (Europe), or internationally between economic regions (USA – Europe). Examples of international movements include the introduction of oysters to Europe from America during the 19th and 20th centuries, and more recently large-scale translocation of seed mussel from UK to Eire, and Ireland to the Netherlands.

Although the majority of movements of shellfish for aquaculture are arguably all driven by economic reasons (Mortensen *et al.*, 2006), some recent stock transfers have been made because there is a shortfall in local supply. This reflects both the variable nature of recruitment to wild sources of stocks of seed shellfish and the lack of commercially cultivated juvenile shellfish for some species, which are often uneconomic to produce.

Details of movements between ICES countries are hard to collate, largely as there is no formal arrangement for all of these transfers to be recorded, and data has to be extrapolated from what information is available. The information offered in the table below is either from data annually presented to the EU reference laboratory at La Tremblade or from intelligence gained by members of the MASC, and whilst it does give an idea of the extent of these movements, should not be considered definitive.

Table 5.6.1.5.1. Shellfish movements within ICES Countries. Information from Estonia, Finland, Latvia, Lithuania, Poland and Russia is still missing.

	MOVEMENTS OF SHELLFISH			
	Local	National	Regional ¹	International
Belgium	X	X	X	
Canada	X	X		
Denmark	X	X	X	
Estonia				
Finland				
France	X	X	X	X
Germany	X	X	X	X
Iceland	X	X		
Ireland	X	X	X	
Latvia				
Lithuania				
Netherlands	X	X	x	
Norway	X	X	X	
Poland				
Portugal	X	X		
Russia				
Spain	X	X		
Sweden	X	X	X	
UK	X	X	X	X
USA	X	X		X

¹Economic area e.g. Europe.

5.7 Potential effects and implications

5.7.1 Introduction

In this section the 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. Topics to be covered in future years are:

- 1) The definition of a transfer, the border of an area, direct (transferred organism is non-indigenous), indirect (transferred organism carries non-indigenous species as a hitchhiker species [fouling organisms / epifauna and epiphytes, organisms within the soft tissue, cysts in sediment]), transfer of bait.
- 2) What is non-indigenous? (established and not established).
- 3) Which non-indigenous species cause effects and a description of the effects
- 4) What are the effects 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?

- 5) Scientific tools to support policy decisions on cultured shellfish transfer issues (e.g. risk assessment of shellfish transfers).
- 6) Recommendations to farmers and policy-makers
- 7) Conclusions

A start was made on the potential genetic implications of transfers for wild and cultured stocks of shellfish. And some relevant new information about transfers was summarized.

5.7.2 Potential genetic implications for wild and cultured stocks

Results of the EU project GENIMPACT are summarized below.

GENIMPACT; WP1 Genetics of domestication, breeding and enhancement of performance of fish and shellfish; Pacific cupped oyster – *Crassostrea gigas*

The pacific oyster was introduced in Europe after the viral disease that crashed the Portuguese oyster (*Crassostrea angulata*) population. Currently there's 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 are found. This hybridization 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 effects of the partial sterility of triploids are poorly known. Another trend to wild populations is the use of tetraploid broodstock when they escape from quarantine, as their fitness relative to diploids and the impact of their breeding with diploids is still unknown.

Beaumont A., Gjedrem T., Moran P., Blue mussel – *Mytilus edulis*, Mediterranean mussel *M. galloprovincialis* (Genimpact final scientific report)

The mussel species *Mytilus edulis* and *M. galloprovincialis* have a huge overlap in space from France to Scotland. *M. edulis* is homogeneous throughout its range while *M. galloprovincialis* is genetically subdivided into a Mediterranean and an Atlantic group. *Mytilus trossulus* also exists in discrete areas. On places where these species occur hybrids are found, but little is known about the precise distributions of both mussel species and their hybrids. Without this basic information it is impossible to estimate the genetic influence of mussel aquaculture on wild populations.

The three main cultivation methods for mussels (bottom culture, suspended culture and bouchot culture) have their own specific characteristics. Therefore there may be a genetic impact as a result of genotype-specific mortality in areas where aquaculture is the major source of mussel biomass.

Hatchery production of mussels is very low in Europe, for this reason the risk of genetic impact from hatchery mussels is currently negligible.

Lapègue S, Beaumont A., Boudry P., Foulletquer P, European flat oyster – *Ostrea edulis* (Genimpact final scientific report)

Ostrea edulis occurs naturally from Norway to Morocco in the North-Eastern Atlantic and in the whole Mediterranean basin. The species has also been introduced in the

United States, from Maine to Rhode Island (1930's and 40's) and in Canada (about 30 years ago). Mediterranean flat oysters have more genetical 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 in France, the UK and Ireland hatcheries are producing flat oyster spat. Hatchery cultured spat has usually a reduced genetic variability and could reduce the variability of the natural population. Polyploid flat oysters could be produced but are currently not farmed.

No large selective breeding programmes have been started for *O. edulis*, but some experiments to improve resistance to *B. ostreae* have been carried out. Results show a higher survival rate and a lower prevalence of the parasite in selected stocks but also a reduced genetic variability of mass selected populations.

Beaumont A., Gjedrem T. Scallops – *Pecten maximus* and *P. jacobaeus* (Genimpact final scientific report)

Scallop spat is obtained from wild-captures and from hatcheries. Hatchery scallops can easily escape from farms, but because scallop aquaculture is very small-scaled in Europe (213 tonnes in 2004 whereas the landings of captured fisheries exceeded 50000 tonnes), the effect on wild populations is not significant.

5.7.3 New information that was published after the WGEIM 2006 report

Wijsman and Smaal (2006): In Irish and UK marine waters, 74 exotic species are present, of which 22 are not found in the Oosterschelde. None of these 22 exotic non-indigenous species were either found on the mussel plots in Ireland and Wales, nor in the transport samples. This, however, does not completely exclude the possibility of their transport. From literature data and expert judgment we assessed that 14 out of these 22 species there is a chance to survive transport, and establish populations in the Oosterschelde. With respect to the effect, out of the 22 exotic non-indigenous species the possible negative impact is considered high for three species. These are the algae *Alexandrium tamarense* and *Gyrodinium* cf. *aureolum* and the gastropod *Urosalpinx cinerea* (American oyster drill). The algae can lead to toxic blooms and the American oyster drill predated oyster spat and can have a devastating effect on oyster beds. The algae species already occur in and along the North Sea, and could be able to find their own way to the Oosterschelde. The American oyster drill has been found locally on the Essex and Kent coasts at the East coast of the UK, and precautions are taken to prevent dispersal to the mussel production areas.

Wijsman et al. (2007a): In total 51 exotic non-indigenous species are known for the Norwegian coastal waters. Fourteen of these species are new for the Dutch coastal waters and can be regarded as target species, which could be introduced into the Wadden Sea with the import of mussels from Norway. Species with highest chance of successful introduction are the algal species *Aglaothamnion halliae*, *C. fragile* ssp *scandinavicum*, *Verrucophora farcimen*, *Karlodinium micrum* and *Olisthodiscus luteus*, the polychaete *Scolecopsis korsuni* (because of the lack of information on this species and the precautionary principle that is used in this study) and the goose barnacle (*Lepas anatifera*). Species with the highest potential impact once introduced are the algal species *Verrucophora farcimen* and *Olisthodiscus luteus*, the American lobster (*Homarus americanus*), the king crab (*Paralithodes camtschaticus*) and the Manila clam (*Ruditapes philippinarum*). Because of the lack of information also the polychaete *Scolecopsis korsuni* is scored as a species with potential high impact (precautionary principle).

Wijsman et al. (2007b): In total 41 exotic non-indigenous species are known for the Swedish coastal waters. Ten of these species are new for the Dutch coastal waters and can be regarded as target species, which could be introduced into the Wadden Sea with the import of mussels from Sweden. Species with highest chance of successful introduction are the algal species *Verrucophora farcimen* and *Aglaothamnion halliae* and the crustacean *Pilumnus spinifer*. Species with the highest potential impact once introduced are the algal species *Verrucophora farcimen*, *Oxytoxum criophilum*, *Pleurosira laevis* *Codium fragile* and the trematode *Pseudobacciger harengulae*. The study shows that the algae *Dissodinium pseudocalani*, *Oxytoxum criophilum*, *Pleurosira laevis*, *Verrucophora farcimen* and *Codium fragile* and the trematode *Pseudobacciger harengulae* present most risks.

The risk assessments of these studies concluded that transport of mussels from Ireland, the UK, Sweden and Norway to the Dutch production areas can be allowed.

5.8 Introduction of Alien species, hitch hikers and pathogens in Aquaculture

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) will focus on transfers with their resultant impacts and consider the long-term impacts of introductions and transfers of shellfish, such as *Crassostrea gigas* within and among ICES countries.

The concerns expressed regarding transfers and introductions are generally related to ecological impacts, genetic aspect and spreading of pathogenic agents.

There should be a presumption against routine introductions and transfer of molluscan shellfish; these 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.

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).

Consultation on an introduction should be full, objective, be universally applied, follow full risk assessment and if approved, be so under quarantine. Imports of shell-

fish 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 below.

5.8.1 Identification of risks

- Certain fish and shellfish species of commercial value may be introduced into ICES waters carrying pathogens harmful to themselves, indigenous fishery and aquaculture stocks.
- In addition, some may reproduce and invade the territory of indigenous competitors. There is also the further risk of inadvertent introduction of hitchhiker species with consignments.
- Legislation is not fully integrated to prevent risks associated with transfers and introductions.
- There is a perceived 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.
- There are existing powers e.g. in the UK under The Wildlife & Countryside Act to prevent introductions; whether it covers all of the above risks is unclear.

5.8.2 Examples of introductions and resultant impacts:

Transfers in marine aquaculture occur routinely, frequently moving shellfish (transplanted) from one location to another within their native distribution range. For example, shellfish spat (seed or spawn) may be dredged from subtidal beds and moved to areas for cultivation. Apart from the physical impact of dredging on the natural habitat, there are concerns about genetic impacts, pests and diseases associated with these aquaculture transfers.

- 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*, *Crepidula 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.
- 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).

- More recently when checking guidelines on introduction of *Crassostrea gigas* (gigas) spat to Scotland from Jersey in the Channel Islands for on-growing, 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 of transmitting the pathogen to naïve populations; having a long-term detrimental effect on multiyear classes in the area of destination and beyond. The *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* spp 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 *gigas* from France via Jersey could have a long-term detrimental effect on naïve cultivated *gigas* in Scotland and elsewhere; however current legislation allows such movements, allowing free trade at the expense of a precautionary approach.
- 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 preventive measure would be to prevent the introduction of *Virginica* into Scotland.
- The blue mussel *Mytilus edulis* is the endemic and dominant species of mussel in Scotland, and production was until recently thought to consist exclusively of this species. However, blue mussels are now recognized as including three distinct species: *Mytilus edulis*, the commonly cultivated species in the North Atlantic and the North Sea; *Mytilus galloprovincialis*, the target species for aquaculture in the Mediterranean, and *Mytilus trossulus*, which is most common in the Baltic and in areas of Canada where it is of lesser commercial interest as a result of its generally thinner shells and lower meat contents Dias *et al.* 2008. 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, this makes it difficult to distinguish the species and their hybrids based on shell shape alone. Recent research on the distribution of *Mytilus* species in Europe has been greatly facilitated by modern 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.* 2008. Recent reports by Scottish growers of fragile-shelled *Mytilus trossulus* which would break during grading, together with the identification of *Mytilus*

galloprovincialis in cultivation areas, has raised important questions relating to sustainability of blue mussel cultivation in certain countries, and the risks associated with transfers of seed. In a few sea lochs in Scotland, *trossulus* appears to be moved from place to place with transfers for cultivation purposes, all of which seem to have connections through movement of mussel stock.

- It is also found in some west coast marinas, suggesting that it might be movable on vessels. It has not yet been found in wild populations, even where adjacent cultivation ropes contain large proportions of *trossulus*.
- There is no evidence of displacement or damage to wild populations, and therefore it does not currently fall into the definition of invasive.
- It is therefore an aquaculture problem
- Beaumont (2000) reviewed the potential genetic consequences of transfers and introductions of scallop species. (There have been a number of introductions of scallop species in recent years, for example *Argopecten irradians* has been introduced to China from the USA, and *Patinopecten yessoensis* has been introduced into France and Western Canada from Japan. Details of known introductions of scallops are given in Appendix Table 1 and the known instances of transfer of scallops are given in Appendix Table 2.)
- To predict the genetic consequences of transfers, information on genetic 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 scallop populations and scallop subspecies. Other considerations considered are the numbers of individuals transferred and whether they are wild stock or hatchery product. Loss of genetic diversity is difficult to avoid in hatchery conditions although there are also ecological advantages to using disease-free 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) recommend that potential risks and consequences of hybridization should be experimentally assessed before introductions of scallops are carried out. Hybridisation is unpredictable and can lead to loss of genetic diversity or breakdown of co-adapted gene complexes. The use of sterile triploid scallops for introductions to avoid hybridization and reduce ecological impact has merit but reversion to diploidy may occur.
- *Mytilus edulis* living intertidally is often infested by macroparasites such as copepods, trematodes and polychaets (Lauckner, 1980, 1983). With increasing distance from coast (subtidal and offshore) mussels infestation is reduced in prevalence and intensity (Buck *et al.*, 2005). In some European countries juvenile blue mussels are dredged from the intertidal region and transferred to licensed plots subtidally when using the on-bottom cultivation technique. However, these local transfers of mussels originating in the intertidal are supporting the transfer of parasites subtidally.
- The transportation of toxin producing algal species and their resting cysts, e.g. from paralytic shellfish poisoning toxin producers (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). This is also

the current situation in certain ICES countries. Additional risks involve the resting cells of toxic algae, capable of surviving for years in the sediment (Tillmann and Rick, 2003) below or in the vicinity of aquaculture installations. When favourable growth conditions return, the cysts may germinate providing a reservoir capable of reinoculating the water with swimming cells that can subsequently bloom (Mons *et al.*, 1998). This can lead to extended or, at times, permanent closure of production areas.

- In the UK, recent guidance provided by the Alien Species Group on behalf of the UK 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 *gigas* on the red list as there was some disagreement as to whether there was scientific evidence to support it being on the list.

5.8.3 Risk Assessment

The strategy and principles to be followed by Directive 2006/88/EC involve; prevention of introduction and transmission of disease, such that the burden to the public and private sectors is proportionate, finding the balance between control of pathogens and over-regulation and ensuring that regulation and surveillance is based on a transparent assessment of disease risk. An essential part in development of any risk based assessment (RBA) model is to ensure that it accurately identifies and quantifies those risks associated with all farms within a zone and provides early detection of disease. Risk assessment requires regular review as industry practices evolve, increasing or decreasing risk on farm sites. Reference should be made to the OIE and ICES codes of practice as guidelines in the production of defensible practices.

Each farm is to receive a ranking (high, medium or low) based on criteria developed at the surveillance work stream workshop, frequency of inspection to be determined by the ranking of each site (Annex III of 2006/88/EC).

5.8.4 Identification of Risk Factors

A risk based assessment workshop agreed a list of risk factors to be applied to all aquaculture production farms. These were ranked into high, medium and low categories.

- The list of high risk factors included; risk of introduction, risk of spreading, farms importing live animals from third country or ap-

proved zone/compartiment and super spreaders (movements to more than 10 destinations).

- Medium risk factors included; importing live animals from an approved member state, proximity to processors, high contact through animal movements (3 or more source/destinations sites), and high contact through water e.g. farms less than 1 km apart in coastal zone or downstream of other farms on a river.
- Low risk factors included, poor biosecurity or husbandry, i.e. those farms promoting conditions conducive to disease expression.

5.8.5 Conclusion

The transfer or movement of shellfish within and between sites on local, regional and international scale poses the greatest risk to introductions of non native species, pests and pathogens to the environment.

Powers are needed to: prevent introductions and subsequent transfers of alien species; ensure a disease free status by introducing only from disease free sources; where necessary, allow for the set up of temporary quarantine facilities through the F1 generation for the introduction of disease free stocks of species– and only those which will not reproduce nor change in genetic composition and seed or prevent seed to the wild, and prevent the inadvertent introduction of pests and hitch hiker species with consignments.

If there are good commercial reasons for the introduction of a species, a robust standard of risk assessment should be applied, prior to release, to ensure that ecosystems are protected. Risk based surveillance is now an animal health requirement under Council Directive 2006/88/EC in the prevention and control of certain diseases and models produced by each country should be designed to identify and quantify risks of disease introduction and spread. Historically different countries have failed to achieve this e.g. introduction of *gigas* to Europe for cultivation where it has successfully reproduced, as stocks of native or Flat Oysters (*Ostrea edulis*) have declined. *Gigas* may provide a good alternative supply of oysters to the native Flat Oyster, however the original aim was not to replace *edulis* with *gigas* but to supplement *edulis* until *edulis* stocks were rejuvenated. Unfortunately the alien *Bonamia* pathogen was introduced; decimating *edulis* stocks and e.g. France has become almost reliant on *gigas*, as markets evolved separately (driven by availability and price) which was not the original plan. It would now be near impossible to remove *gigas* from certain areas of France if a disease resistant strain of *edulis* was developed and rejuvenation of stocks attempted (Héral, Deslous-Paoli *et al.*, 1986).

Transfers of shellfish are made routinely at all levels, local...; by countries of differing environmental and disease status, highlighting the real risks of introducing pests, parasites and diseases, There is a need for coordination of the application of legislation and codes of practice within and between countries; to minimize introduction and spread of invasive species and pathogenic organisms.

5.9 Recommendations

- 1) The WGMASC recommends that ToR c (combined ToRs c) and d) from 2008 report) remain active to complete a review on the significance of bivalve aquaculture transfers between sites (local, national, international) to wild and cultured bivalve stocks. The focus of the ToR will be on guidelines and records in ICES countries related to the transfer of cultured species, and on effects of shellfish relocations on the geographic distribution of marine organisms, indigenous shellfish stock traits (genetic, physiological, morphological, recruitment, competition, and predation) and the potential implications for regional shellfish culture operations are reported.
- 2) The WGMASC recommends that key persons of WGEIM and WGITMO dealing with the introduction of aquatic exotic species via shellfish transfers should be invited to the next WGMASC meeting to participate in preparing a joint report, identify information gaps and recommend specific research goals and management advice.
- 3) 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.
- 4) Proper risk assessment should be undertaken, irrespective of cost, to ensure safety to ecosystems, as the long-term environmental and financial costs from introductions is unquantifiable in the long-term.
- 5) Consultation on applications should be vigorous, be universally applied and be objective; and there should be a presumption against them, unless good scientific evidence proves otherwise.
- 6) There is a need to regularly review and update regulations to account for and minimize the potential impact of emerging environmental or disease issues.
- 7) Monitoring of translocation of spat inter and between countries should be implemented to minimize transfer related risks and minimize the impact of e.g. Germany who routinely imports mussels from Ireland and Denmark, with resultant concerns regarding speciation or the introduction of pests or diseases
- 8) Consideration should also be given to the risk to native stocks from interbreeding. The resultant progeny invading ecosystems possibly being infertile, creating an imbalance within an ecosystem. If not infertile they may replace indigenous stocks

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5.11 Annex 1 – A guide to temporary quarantine conditions

- 1) The facility must be authorized as an Aquaculture Facility and all movements of live animals into the facility are to be recorded in the official Movement Record Book supplied.
- 2) The facility will be open to inspection by inspectors as deemed necessary.
- 3) The animals should be held in isolation in a system approved by the competent authority.
- 4) No animals or eggs are to be released alive from the facility without prior written approval.
- 5) All unwanted biological material must be removed in leak-proof containers and destroyed by incineration or autoclaving.
- 6) Access to the facility must be limited and come under the supervision of a nominated person.
- 7) A sign should be placed at all entrances stating 'Quarantine Area – Restricted Admittance'.
- 8) 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.
- 9) 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 of the evidence of and effect of climate change on shellfish aquaculture distribution and production in ICES and countries worldwide. (ToR e)

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. Regardless of the source of climate change, interactions with shellfish aquaculture are unavoidable.

The IPCC analysed 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 fre-

quency of large precipitation events have increased significantly in many ICES countries. These changes are linked with high confidence to increased run-off and the occurrence of earlier spring discharges and shifts in the geographic distribution and abundance of algae, plankton and fish.

The issue of climate change and the possible impact of temperature rise and hydrodynamic changes on shellfish aquaculture have received little direct research effort. However, climate changes will ultimately impact which species are suitable for farming in a given region and will indirectly influence other factors that influence aquaculture, such as primary production, microalgal biodiversity, the presence of nuisance species, oxygen levels and the incidence of harmful algal blooms (University of Victoria, 2000, Canadian Institute for Climate Studies 2000). The increased carbon dioxide would cause an acidification of the oceans, which may reduce the shell growth of molluscs (Gazeau *et al.*, 2007). Climate change may also cause sea level rise and alter salinity, weather extremes, storm surges, tidal regimes, waves and coastal erosion, all of which can impact shellfish aquaculture with a largely unknown net positive or negative result. It is believed that climate change will impact shellfish aquaculture, particularly in the intertidal zone, but knowledge is needed to more fully identify the threats and potential opportunities. Our task is to consider the current scientific evidence of and effect of climate change in ICES countries and worldwide. For example, can summer mortalities in *C. gigas* be attributed to climate change in certain European countries or simply be a result of poor broodstock selection? To address this ToR, any available evidence on climate change impacts on cultured species needs to be accumulated and assessed. This includes collecting information related to a recent 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." Work by the WGMASC, included reviewing reports on present climate change patterns and specific marine parameters in the North Atlantic that are affected and which may affect shellfish aquaculture. A starting point was to examine predictions of potential changes in the marine environment as revealed by different model scenarios. This report will be further expanded in the coming years.

6.2 Related ICES reports and other ICES activities on climate change

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

The ICES Benthos Ecology Working Group (BEWG) initiated the Workshop on Climate related Benthos Processes in the North Sea (WKCBNS) held during 8–11 December 2008 in Wilhelmshaven, Germany, to discuss further research activities concerning the North Sea benthic ecosystem. This report contains 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 key benthic processes affected by climate change, and a draft of small-scale "box" areas in the North Sea, examples of modelling approaches. Some of the main findings of the NSBP related to climate change were: (i) changes in the latitudinal distribution of some benthic species, (ii) changes in community composition, and (iii) the importance of large-scale hydrographic variables, such as bottom temperature, for the structuring of benthic (and fish) communities in the North Sea. Information from this report can be reviewed and used to expand on the climate change effects for shellfish aquaculture.

6.2.2 2008 report from WGEIM

The Working Group on Environmental Interaction in Mariculture (WGEIM) has a new ToR e for 2009 which concerns potential impact of climate change on aquaculture activities. In this ToR they will focus on aquaculture species found on the boundaries of climatic regions, as they may be at risk of greatest impact as a result of climate change. Topics include: changes in geographical distribution of aquaculture species as a result of changes in climate related environmental variables (rainfall, sea temperature), the potential to culture new species, the influence on harmful algal blooms, the impact of increased run-off might have on shellfish waters classification and the impacts increased storminess might have on mariculture activities. This ToR shows a substantial overlap with the work carried out by the WGMASC in the present ToR. As the WGMASC is already in its second year with the work there is a danger that the WGEIM is going to repeat some parts that concern shellfish. To promote an integrated approach it is recommended that there is sufficient communication on this subject between WGMASC and WGEIM. A possible way to achieve this is to have a joint meeting in 2010.

6.2.3 Steering Group on Climate Change (SGCC)

The SGCC met for the first time in 2008. 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 currently 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.

6.2.4 Joint PICES/ICES Working Group on Forecasting Climate Change Impacts on Fish and Shellfish [WGFCCIFS]

A joint meeting between PICES and ICES Working Group on Forecasting Climate Change Impacts on Fish and Shellfish [WGFCCIFS] will be established (Co-Chairs: A. Hollowed, USA, Manuel Barange, UK, Suam Kim, Korea, and Harald Loeng, Norway), and will meet on 21 June 2009 one day prior to the GLOBEC Synthesis meeting in Victoria B.C, Canada. Their ToRs include the promotion of research on climate change impacts on marine ecosystems by scientists in ICES and PICES member nations through coordinated communication, exchange of methodology, and organization of meetings to discuss and publish results; in collaboration with relevant expert groups in PICES and ICES, develop frameworks and methodologies for forecasting the impacts of climate change on marine ecosystems, with particular emphasis on the distribution, abundance and production of commercial fish and shellfish; plan for a

science symposium in early 2010 to present, discuss and publish forecasts of climate change impacts on the world's marine ecosystems, with particular emphasis on commercial fish and shellfish resources. The work of WGMASC can contribute to these ToRs.

6.3 Climate change: Model scenarios

Modelling of different scenarios (SRES) indicates that for the period 2090 to 2099 the global air temperature will be 1.8 to 4.0°C higher than compared with that from 1980–1999. The greatest warming will occur in the north and least at the southern ocean. Projected changes in the marine environment during this period include;

- sea ice cover in Arctic will be reduced or disappear, whereas no reduction is expected in the Antarctic
- a sea level rise of 0.18 to 0.59 m is expected
- more extreme weather conditions including heavy precipitation and wind events are expected
- the run-off of freshwater to marine areas will vary significantly from area to area (e.g. the Mediterranean will have a 40 % reduction in run-off and the North Sea will have a 10–40 % increase in run-off)
- change in the geographical range of organisms, diversity, and ecological structure and function
- coastal area are expected to be flooded and any industries in these areas (i.e. shellfish production) are most vulnerable to climate change
- the temperature increase and increased run-off may affect the formation of pycnoclines in coastal areas. This can have implication for the transport of the nutrient rich water to the photic zone that supports microalgae production. A strong pycnocline may increase the frequency of oxygen depletion in specific areas
- a higher frequency of wind events (storms) will affect structures currently used for shellfish aquaculture
- heavy precipitation may increase the run-off of nutrients, supporting a higher primary production. Floods as a result of heavy precipitation may reduce food safety and sanitary quality, as a result of run-off of sewage

The ocean is becoming more acidic as increasing atmospheric CO₂ is absorbed at the sea surface. Models and measurements suggest that surface pH has decreased by 0.1 pH unit since 1750. Continued acidification will reduce the ability of the ocean to take up CO₂ from the atmosphere, which will have feedbacks to future climate change, further accelerating the accumulation of CO₂ in the atmosphere. Future increases in acidity may have major negative impacts on shellfish aquaculture within this century, e.g. by causing reduced calcification.

During the last century the global average sea surface temperature has increased 0.6±0.2°C. This has important implications for the marine ecosystem. On the scale of marine ecosystems, the effects of climate forcing include:

- changes in biogeographical, physiological and species abundance and range
- changes in seasonal cycles (e.g. food production, migration, reproduction)
- change in foodweb organization and trophic interactions

- changes in the distribution and intensity of Harmful Algal Blooms

6.4 Available evidence on climate change effects on aquaculture

In general, any evidence presented on climate change impacts on shellfish aquaculture is not based on cause – effect linkage, but on simple correlation. Considering that these correlations can reflect autocorrelations, anti-aliasing, and/or random processes, the interpretation of climate change related correlations requires awareness and must be supported by reasonable biological understanding of the systems.

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). Population dynamics of cold-water bivalve species are strongly related to temperature and mild winters in northwestern European estuaries result 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. Mortality of juvenile bivalves appears to be related to food availability and reproductive strategies are closely linked to exploiting spring phytoplankton bloom and avoiding peak predator abundance. 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).

To study possible causes of recent bivalve recruitment failure, Beukema and Dekker (2005) compare long-term datasets (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*) on Balgzand, a tidal-flat area in the westernmost part of the Wadden Sea. 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 appears to be largely governed by the warming climate. The recent disappearance of *M. 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 increasing summer maximal temperatures (Jansen *et al.*, 2006).

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.

Diederich *et al.* (2004) studied how the Pacific oyster (*Crassostrea 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 and analyses of mean monthly water temperatures indicate that strong recruitment coincided with above-average temperatures in July and August when spawning and planktonic dispersal occurs. It was concluded that the further invasion of *C. gigas* in the northern Wadden Sea will depend on high late-summer water temperatures.

Berge *et al.* (2005, 2006) examined interannual variations in ocean temperatures and the increased northward volume transport of Atlantic water and suggested that a recently discovered population of *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 those 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 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. *C. gigas* were first discovered in the Norwegian Skagerrak in 2005 and recent surveys have revealed that they have become established in many areas along the Scandinavian coasts. Larval dispersal from other areas, combined with warmer summers, appears to be facilitating survival. *C. gigas* tends to settle in the same areas as *M. edulis* and these native species will likely diminish through overgrowth by oysters, food competition and consumption of mussel larvae (Nehring 2003).

The native European flatoyster (*Ostrea edulis*) has its northern distribution in Scandinavia where it historically has been cultured mainly in habitats that have higher summer temperature than the coastal and oceanic environment (Strand and Vølstad, 1997). Increasing seawater temperatures and frequency of extreme warm summers during the last decade have supported the development of populations of the oyster in coastal waters of this region.

Bivalves are a net source of CO₂ to the atmosphere via respiration and the deposition of calcium carbonate in shell material, which induces a shift in the seawater carbonate equilibrium to generate, dissolved CO₂. 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 CO₂ sources and provided compelling evidence that bivalve molluscs can markedly influence inorganic carbon cycling by generating CO₂ to the surrounding water. This biogenic CO₂ 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).

Recent work describes physiological effects from reduced pH indicating potential effects from acidification. Michaelidis *et al.* (2005) and Berge *et al.* (2006) found that acidification negatively affected mussel growth and suggested that this is related to physiological and metabolic depression. Gazeau *et al.* (2007) showed that calcification rates in *Mytilus edulis* declined linearly with increasing CO₂ levels, juveniles being particularly sensitive to acidification. Bibby *et al.* (2008) investigated immune response in mussels (*Mytilus edulis*) exposed to acidified (using CO₂) seawater, and suggested that ocean acidification may impact the physiological condition and func-

tionality of the haemocytes and could have a significant effect on cellular signalling pathways, particularly those pathways that rely on specific concentrations of calcium, and so may be disrupted by calcium carbonate shell dissolution.

6.5 Bivalve tolerance of temperature change

The upper temperature tolerance of different bivalve molluscs can serve as a first-order approximation of their susceptibility to global warming trends. The WGMASC will review the upper temperature tolerance of a wide range of bivalve species in the coming years. However, confounding factors also need to be considered as they can make it difficult to predict species responses to regional temperature variations. For example, a bivalve species residing in a more tropical climate is less able to adapt to temperature variation than the same species residing in temperate waters, owing to the wider thermal tolerance of the latter (Compton *et al.*, 2007).

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

An 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.

6.7 Recommendations

- 1) The implications of climate change to shellfish aquaculture exist within a much broader context of anticipated physical and biogeochemical alterations in coastal marine ecosystems. The WGMASC recommends the close linkage of knowledge and advice generated under our ToR with all relevant ICES activities on related subjects such as the work planned by WGEIM, SGCC and the Joint PICES/ICES Working Group on Forecasting Climate Change Impacts on Fish and Shellfish. To achieve an integrated approach for the work on shellfish aquaculture WGMASC recommends having a joint meeting of WGMASC and WGEIM in 2010.
- 2) The WGMASC should continue to 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. Topics yet to be fully addressed include, but are not limited to:

- effects on shellfish resulting from climate change related changes in primary production, run-off, salinity, nutrient dynamics, acidification of the ocean, etc.
- potential for risk analysis approaches for assessment
- potential opportunities for positive effects such as exploiting new species for aquaculture in northern countries.
- contingency planning to minimize impact

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Annex 2: Summary of Theme Session on “Ecological Carrying Capacity in Shellfish Culture” held at the ICES ASC 2008 in Halifax

ICES ASC 2008 Theme Session H

Ecological Carrying Capacity in Shellfish Culture

Conveners: Francis O’Beirn (Ireland) and Peter Cranford (Canada)

Introduction

Aquaculture is the fastest growing food-producing sector in the world and is the only means of filling the growing gap between consumer demand and seafood production from traditional capture fisheries. While there is a clear need for the continued worldwide expansion of aquaculture to fill this gap, this development needs to be promoted and managed in a responsible manner that minimizes negative environmental impacts. To ensure that human activities are carried out in a sustainable manner, maritime policies (e.g. Canadian *Oceans Act* and EU *Water Framework* and *Marine Strategy Directives*) all include as essential components; 1) a knowledge-based approach for decision-making, and 2) an ecosystem-based approach for integrative management. Environmental concerns regarding shellfish culture are related primarily to how the culture interacts with, and potentially controls, fundamental ecosystem processes. Many cultured bivalve species have an exceptional capacity to filter large volumes of water to extract phytoplankton and other suspended particulate matter. While ecosystem-scale changes may result from their considerable role as biofilters, bivalves also excrete large quantities of ammonia and biodeposit undigested organic matter on the seabed. Observations of culture impacts have generally focused on small-scale benthic impacts. Given the intensity of culture in some regions, a more ecosystem-based perspective is required based on the development of prognostic site assessment tools and practical ecosystem performance indicators. Owing to the number of ecosystem processes potentially influenced by mussel aquaculture, ecosystem modelling is an essential tool for understanding and predicting ecosystem interactions.

A fundamental difference between the management of wild fisheries and aquaculture is that the former aims to maximize the catch of the target species without impacting the population or the ecosystem, while the latter strives to maximize stock addition within a given area without causing similar types of impacts. A goal of aquaculture management is to have tools available that can predict and measure the capacity of an area to support the cultured species. This “carrying capacity” concept is rapidly evolving from an anthropocentric focus on maximizing aquaculture production to an ecosystem-based management approach that focuses on ecological sustainability. Carrying capacity research has largely focused on identification of production carrying capacity, which is the maximum sustainable yield of culture that can be produced within a region. Ecological carrying capacity is the level of culture that can be supported without leading to significant changes to ecological processes, species, populations or communities in the growing environment. The development of ecological carrying capacity indicators and models is still in its infancy but has the potential to feed into ecosystem-based management systems for marine areas. In addition, this work reflects the ideals and goals of the ecosystem approach to aquaculture and fisheries management. The ability to predict ecological carrying capacity is crucial to expanding large-scale bivalve aquaculture operations and has the potential to feed into ecosystem-based management systems. A range of topics and gaps in knowledge

need to be addressed to progress the science of ecological carrying capacity in shellfish including, *inter alia*, the following;

- development of guidelines towards defining an “unacceptable” ecological impact, based on theoretical and socio-economic considerations, and identification of critical limits (i.e. operational standards or thresholds) at which the levels of shellfish aquaculture stress indicate a disruption of the system warranting management actions,
- research on the development, value and application of predictive ecological models of shellfish aquaculture systems,
- time-series observations of ecological responses to shellfish aquaculture development and validation of model predictions,
- site-specific factors affecting ecological carrying capacity,
- direction for scientists from stakeholders (e.g. habitat and farm managers and nongovernmental organizations) on potential ecosystem components that need to be evaluated in unbiased ecological carrying capacity assessments, and
- discussion on how models of aquaculture systems complement the ecosystem approach to marine management.

Overview

Within the theme session there were 14 oral presentations and 5 poster presentations. The presentations broadly discussed issues surrounding the estimation of carrying capacity ranging from production estimates (Smaal and Silvert; Gubbins *et al.*) to full ecological models with subsequent estimates of shellfish production and ecological carrying capacity (Jiang and Gibbs). The simple model approaches described by Smaal and Silvert and Gubbins *et al.* for estimating carrying capacity are based on determining the risk of bay-scale phytoplankton depletion from excessive bivalve grazing. Although these approaches are directed primarily at ranking the relative risk of culture activities in different settings (Gubbins *et al.*) and for optimizing shellfish yields in a given area (Smaal and Silvert), they provide information on the potential effect on the base of the marine food chain (phytoplankton), which is obviously relevant to ecological stability.

Jiang and Gibbs demonstrated that by running a full ecological model of a system that the production capacity of a system in New Zealand was 350T/km²/year. Whereas, when the ecological carrying capacity was factored in the actual bivalve production was reduced to 65T/km²/year. They defined this ecological carrying capacity limit based on significant predicted changes in major energy fluxes or the structure of the foodweb. Model predictions based on large-scale mussel culture included a decrease in the mean trophic level of the ecosystem, an increase in total yield, throughput and efficiency and a replacement of zooplankton by the cultured mussels. These capacity estimates and predictions have not yet been validated as the production levels have so far remained below the lower ecological estimate.

Byron *et al.* introduced the various definitions of carrying capacity (Physical, production, ecological and social) and outlined a proposed approach towards the development of shellfish aquaculture in Rhode Island, USA by applying the following Soto (2007) principles;

- aquaculture should be developed in the context of ecosystem functions and services with no degradation of these beyond their resilience capacity,

- aquaculture should improve human-well-being and equity for all stakeholders,
- aquaculture should be developed in the context of other sectors, policies and goals.

However, the development of a sustainable long-term management plan is a difficult course to navigate. Recent advances in the measurement and application of carrying capacity provide some guidance. Modeling ecological carrying capacity with feedback from stakeholders in the system holds the most promise for meeting Soto's (2007) three principles of aquaculture, but as a result of its newness, is also the least understood and practised. Rhode Island is an excellent venue for testing this approach so that it might be made available to those in other areas who see the value of stakeholder involvement in a science-based effort to find the proper limits to aquaculture in their local waters.

A number of studies described the influence that filter feeding organisms (including culture organisms, e.g. oysters and mussels) have on specific species, populations, communities, habitat or ecological processes. These include the influence of shellfish production on nutrient dynamics (Andersen *et al.*, Brigolin *et al.*), phytoplankton abundance, size structure and/or production (Andersen *et al.*, Cranford *et al.*, Cugier *et al.*, Grangere *et al.*), zooplankton (Andersen *et al.*), secondary production (Archambault *et al.*), and the effects of shellfish biodeposition on the benthos (Andersen *et al.*, Weise *et al.*, and McKindsey *et al.*). Andersen *et al.* examined the effects of mussel culture in Newfoundland (Canada) on a range of system components and processes and concluded that there was potential for significant effects on planktonic processes, but that these effects are controlled by bathymetry and stratification. Grangeré *et al.* developed an ecosystem box model of the nitrogen cycle in the Baie des Veys, France and concluded that the main variables influenced by the presence of oysters were phytoplankton and wild suspension-feeders. The higher grazing pressure on phytoplankton induced by the addition of cultivated oysters as well as the trophic competition existing between wild filter-feeders and cultivated oysters explained the strong decrease in phytoplankton biomass and production and wild filter-feeder stocks. This approach suggested that the shellfish stocking in that system was beyond the ecological carrying capacity. The analysis of the year-to-year variability of river inputs indicated that the main fluxes of this ecosystem tended to increase with the increase of external inputs. However, the influence of cultivated oysters seemed to be more important than that of the environment beyond a threshold value of river inputs around 3000 T N y⁻¹. In the Baie des Veys, river inputs were seldom lower than 3000 T N y⁻¹, so, the nitrogen cycle in the Baie des Veys was influenced more by the cultivated oysters than by the environment. Finally, the comparison of fluxes between different ecosystems improved knowledge of the influence of cultivated species on their respective environment and the effect of different modelling approaches (phytoplankton vs. seston as mussel food). However, the comparison was difficult as a result of the numerous differences existing in the structure and the functioning of these cultivated areas. Trophic interactions were also examined in Baie Mont-Saint-Michel (France) by Cugier *et al.* who employed coupled biological and hydro-sedimentary models to examine the relative ecological roles of wild, cultured and invasive filter-feeders. They concluded that filter-feeders strongly control chlorophyll levels in this bay. If all the filter-feeders were removed from the bay, maximum chlorophyll should be 2 to 3 times higher in most part of the bay. The invasive gastropod, *Crepidula fornicata* was deemed to have a dominant effect in the western bay, where this species is concentrated, while wild native filter-feeders have their main effect in

the east. Filtration pressure appears to be partially compensated by the production and deposition of organic matter (faeces and pseudofaeces) by cultivated and invader species. Remineralization of this matter seems able to sustain chlorophyll levels. Cugier *et al.* highlighted the relative pressure exerted by each category of benthic filter-feeders on the pelagic ecosystem but not on each other through trophic relationships. Future research activities by this group will address this shortcoming by developing eco-physiological models for oysters, mussels and *Crepidula*, which will also be used to explore a number of farm management scenarios.

Some presentations coupled physical models with production estimates. In particular, the interaction between shellfish culture and physical attributes of systems was examined to determine how shellfish production is influenced. Filguera and Grant indicated that artificial upwelling of nutrient-rich deeper water stimulated phytoplankton growth in a Norwegian fjord, with a potential increase in production carrying capacity for mussel cultivation. With the aim of evaluating aquaculture effects and assisting in the development of sustainable mussel culture, a model was developed which represented regions of the fjord. Subsequent manipulations of the model maximized mussel production in the upper fjord based on projected nutrient phytoplankton enhancement by the upweller with a view to efficiently managing mussel production in the fjord. Grant *et al.* compared the results of this model to those of a fully spatial model of the entire fjord. The range of regeneration times in stratified waters bodies will also have a bearing on the capacity of the system to produce shellfish and the degree of interaction between cultured shellfish and other filter feeding organisms in a system. For example, Strand *et al.* demonstrated that nutrients in a Norwegian fjord tend to be limiting due partially to the fact that the regeneration times of deposits into deeper waters is protracted. Strand *et al.* also highlight that fjords and coastal waters in Norway are considered to be low-sediment environments with implications for estimates of ecological carrying capacity. Suspended culture of mussels in fjords may change the ecological energy flow in the ecosystem because the littoral zone is short and natural stocks of benthic suspension-feeders are relatively low.

McKindsey *et al.* and Weise *et al.* focused their presentation on the influence mussel biodeposition has on the benthos and on attempts to model these effects. Information relating to biodeposition effects will go some way towards determining the environmental carrying capacity of a site in particular as it relates to the benthos. The dose-response study conducted by McKindsey *et al.* provided quantifiable evidence that species richness will decrease with increasing biodeposition and reiterates the fact that some organisms can be good indicators of environmental stress, both by the presence (tolerance) and extirpation (sensitivity). The results of this manipulative experiment are an important step towards evaluating the environmental carrying capacity of sites for bivalve aquaculture. Further research is needed to extend the generality of the findings beyond site-specific effects, to determine the range of biodeposition increase, as well as to reduce potential experimental artefacts.

Weise *et al.* applied numerical models, developed originally for modelling the distribution of biodeposits around salmon cages, to the distribution of biodeposits around mussel lines. The study demonstrated that the model can be adapted for shellfish culture sites and may be a good tool to investigate the spatial extent of biodeposition. Shellfish-DEPOMOD can predict nearfield effects at a high resolution (metre-scale). Because shellfish culture sites are typically located in shallow coastal areas, this type of resolution is important to adequately model the dispersion of waste material as dispersal of biodeposits may occur over fairly short distances. Although there is an

acknowledged need to more fully understand shellfish farm waste production and resuspension processes, the model presented can be used to estimate the spatial extent of effects. This model, in conjunction with other models/indices that focus on far-field effects (e.g. nutrient cycling, pelagic carrying capacity), can provide industry and ocean management with the tools to efficiently and comprehensively assess effects associated with shellfish culture activities within an ecosystem-based management framework.

Cranford *et al.* presented results from studies at mussel farms in Canada and Norway on the spatial scales of phytoplankton depletion. This study presented new methodologies for mapping the depletion plume and showed that significant phytoplankton depletion from extensive mussel culture activities in Tracadie Bay (Canada) occurs at the coastal ecosystem scale, which confirms model predictions. This study also showed that mussel aquaculture embayments in Prince Edward Island (Canada) that are at the highest risk of significant baywide particle depletion from mussel culture were dominated by picophytoplankton (0.2–2.0 μm cell diameter). This highly novel observation is likely the result of the large-scale removal of larger phytoplankton by mussels and represents a significant ecological destabilization that can be expected to alter competition and predator-prey interactions between resident species.

Conclusions

Ecosystem-based management has become an important concept in coastal zone management, which includes aquaculture. Assessment of aquaculture has occurred mostly at the local scale by measuring the 'footprint' of shellfish farms. Extrapolating these effects up to any larger scale has been limited by identification of a signal attributable solely to aquaculture, and the ability to make meaningful measurements over larger areas. When many local farm units are considered, the scenario is even more complex because their impacts interact as a function of bathymetry, proximity, circulation, and coastal morphology. Several presentations highlight the identification of practical indicators of benthic and pelagic effects of shellfish aquaculture that can be applied at ecologically relevant scales. Modelling can also address the problem of understanding multiple farm interactions and cumulative effects of other coastal zone activities (e.g. eutrophication and invasive species) on a scale relevant to coastal ecosystems. The presentations highlight the importance of having good information pertaining to the hydrological conditions to drive physical models and understand better the interactions within systems.

An important outcome of the session was the acknowledgment that investigators are designing research projects to consider multiple factors influencing the form and function of marine ecosystems. The combination of subjects into single research projects has and will continue to contribute greatly to the understanding of the interaction of human activities in marine systems. These projects will subsequently provide scientifically robust and important information towards the development and management of activities in the marine environment. Carrying capacity research continues to provide information on a system-wide level; however, models are being refined to provide important information on the capacity relating to partitioning on differing spatial and temporal scales.

Annex 3: Agenda

Tuesday 7 April 2009

- 09:00 Installation of computers
- 09:30 Welcome to AWI by Professor Dr Allan Cembella
- 09:45 Introductions and update on ICES activities – Pauline Kamermans
- General discussion of ICES activities
 - Discussion on Terms of Reference to develop work plan, identify subgroups, subgroup leaders and rapporteurs
 - Adoption of agenda
- 10:30 *Health Break*
- 11:00 Subgroup sessions (ToR = WGMASC Term of Reference):
- ToR b: *Evaluation framework for shellfish aquaculture impacts*
 - ToR c) and d): *Aquaculture transfers between sites/countries – guidelines and records and impact on wild stock*
- 12:30 **Lunch**
- 13:30 Continue ToR subgroup sessions
- 15:00 *Health Break*
- 15:30 – 18:00 Continue ToR subgroup sessions

Wednesday 8 April 2009

- 09:00 Plenary – brief overview of work status
- 09:30 Plenary discussion on ToR e: *Effect of climate change on shellfish aquaculture*
- 10:30 *Health Break*
- 11:00 Reconvene ToR subgroup sessions
- 12:30 **Lunch**
- 13:30 Continue ToR subgroup sessions
- 15:00 *Health Break*
- 15:30 Continue ToR subgroup sessions
- 16:00 – 18:00 Plenary discussion of ToR a: *Emerging shellfish aquaculture issues and science advisory needs*

Thursday 9 April 2009

- 09:00 Revision of WGMASC report in subgroups, and reading text of other subgroups.
- 10:00 Plenary Session: review and discuss 1st draft of WGMASC report
- 10:30 *Health Break*
- 11:00 Revision of WGMASC report in subgroups.
- 12:30 **Lunch**
- 13:30 Plenary Session:
- Review and adoption of the scientific text of the report
 - Discussion and drafting of recommendations
 - Prepare Executive Summary
- 15:30 *Health Break*
- 16:00 Plenary Session (cont.):
- Discussion on any new Terms of Reference
 - Discussion on Theme Session for Annual Science Conference in 2010
 - Location of next meeting
- 18:00 Meeting Adjournment

Annex 4: WGMASC Terms of Reference for the next meeting

The **Working Group on Marine Shellfish Culture** [WGMASC] (Chair: Pauline Kamermans, the Netherlands) will meet in there are 2 options (1) Galway, Ireland together with WGEIM, or (2) Oostende, Belgium without WGEIM from ??-?? (to be decided) 2010 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 knowledge and report on the significance to wild stocks of bivalve aquaculture transfers between sites/countries. This will include information on what species are transported where, what records are kept, and what guidelines are in place in ICES countries related to the transfer of cultured species.
- d) review and assess: the potential for transfer of non-indigenous species and diseases; the potential genetic implications for wild stocks; the impact on recruitment to existing stocks by large-scale transfers, and scientific tools for decision support on cultured shellfish transfer issues; and
- e) review the state of knowledge of the evidence for and effect of climate change on shellfish aquaculture distribution and production in ICES and countries worldwide.

WGMASC will report by **DATE** to the attention of the SCICOM.

Supporting Information

Priority:	WGMASC is of fundamental 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.
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<p>Scientific justification and relation to action plan:</p>	<p>Action Plan No: 1.</p> <p>Term of Reference a)</p> <p>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.</p> <p>Term of Reference b)</p> <p>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 on-growing to market size. In addition, it is intended to investigate the sustainable use of oceans by integrating aquaculture and fisheries and assess the potential for combining shellfish culture with other offshore constructions such as renewable energy facilities or any other. The Chair of WGMASC will cross-reference all work with SCICOM and relevant Working Groups.</p> <p>Term of Reference c) and d)</p> <p>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. The significance to wild stocks of such transfers requires information on what species are transported where, what records are kept, and what guidelines are in place in ICES countries related to the transfer of cultured species. 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.</p> <p>Term of Reference e)</p> <p>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.</p>
<p>Resource requirements:</p>	<p>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.</p>
<p>Participants:</p>	<p>The Group is normally attended by some 10 – 12 members and guests.</p>
<p>Secretariat facilities:</p>	<p>None.</p>

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 relevant to WGICZM.
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 5: Recommendations

RECOMMENDATION	FOR FOLLOW UP BY:
1. The WGMASC recommends to continue ToR a to identify and report on emerging shellfish aquaculture issues and related science advisory needs for maintaining the sustainability of living marine resources and the protection of the marine environment.	SCICOM
2. WGMASC work on ToRb is considered complete with a report produced entitled "An Ecosystem-Based Framework for the Integrated Evaluation and Management of the Impacts of Shellfish Aquaculture Activities in the Coastal Zone". The recommended management framework for shellfish culture was designed to be compatible with legislative and policy frameworks and ecosystem management approaches throughout ICES countries. It is recommended that key members leading this ToR synthesize the content of this report with the purpose of publication in an appropriate international journal. The revised manuscript will be presented to all WGMASC members intersessionally for review as co-authors.	WGMASC, SCICOM
3. It is recommended that ICES actively promote the final WGMASC report entitled "An Ecosystem-Based Framework for the Integrated Evaluation and Management of the Impacts of Shellfish Aquaculture Activities in the Coastal Zone." And to establish liaisons with international organizations, convention and panels with interest in regulating aquaculture environmental interactions.	SCICOM
4. The WGMASC recommends that the members of the WGMASC review the state of the knowledge of site selection criteria in molluscan aquaculture with particular reference to accessing and developing offshore facilities as a new ToR b.	SCICOM
5. The WGMASC recommends that ToR c) and d) should be merged and remain active to complete a review on the significance of bivalve aquaculture transfers between sites (local, national, international) to wild and cultured bivalve stocks. The focus of the ToR will be on guidelines and records in ICES countries related to the transfer of cultured species, and on effects of shellfish relocations on the geographic distribution of marine organisms, indigenous shellfish stock traits (genetic, physiological, morphological, recruitment, competition, predation) and the potential implications for regional shellfish culture operations are reported.	SCICOM, WGEIM, WGITMO
6. The WGMASC recommends that key persons of WGEIM and WGITMO dealing with the introduction of aquatic exotic species via shellfish transfers should be invited to the next WGMASC meeting to participate in preparing a joint report, identify information gaps and recommend specific research goals and management advice.	SCICOM, WGEIM, WGITMO
7. The WGMASC recommends to continue ToR e to 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	SCICOM, WGEIM
8. The implications of climate change to shellfish aquaculture exist within a much broader context of anticipated physical and biogeochemical alterations in coastal marine ecosystems. The WGMASC recommends the close linkage of knowledge and advice generated under our ToR e with all relevant ICES activities on related subjects such as the work planned by WGEIM, SGCC and the Joint PICES/ICES Working Group on Forecasting Climate Change Impacts on Fish and Shellfish.	SCICOM, SGCC, WGFCCIFS, WGEIM
9. WGMASC recommends that a joint meeting of WGMASC and WGEIM should be held in 2010.	SCICOM, WGEIM