ICES WGMASC Report 2005

ICES Mariculture Committee
ICES CM 2005/F:05
Ref. G, ACME

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

13–15 May 2005

La Rochelle, France

International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer

International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer
H.C. Andersens Boulevard 44-46
DK-1553 Copenhagen V
Denmark
Telephone (+45) 33 38 67 00
Telefax (+45) 33 93 42 15
www.ices.dk
info@ices.dk

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

Contents

1 Opening of the meeting

1.1 Place and date

The ICES Working Group on Marine Shellfish Culture [WGMASC] held its third meeting in La Rochelle (France) from the 13–15 May 2005 at the Centre de Recherche sur les Ecosystemes marins et Aquacoles (CREMA), IFREMER and CNRS (National Center for Scientific Research).

Special thanks are due to the administrative staff and head of CREMA, who made every effort to arrange an adequate venue at the lab, even during a weekend. The IFREMER Nantes Centre provided a van for transportation from downtown to the lab.

The meeting was opened at 9:30 hrs on Friday 13 May. The Chair welcomed the participants, including two members attending a WGMASC meeting for the first time: Per Dolmer (Danish institute for Fisheries research, Denmark) and Jose Fuentes (Consellería de Pesca e Asuntos Marítimos, Galicia, Spain).

1.2 Attendance

Seven people representing six countries attended the 2005 meeting of WGMASC (see detailed list in Annex 1). Other members, who were unable to attend, sent apologies (B. Bayne, P. Cranford, S. Robinson, S. Gollasch, and R. Wenne). The WGMASC noted that two countries accounting among the largest shellfish producers were represented for the first time, following efforts to promote membership at the last ICES Annual Science Conference in Vigo (Spain). The Chair expressed concerns about the poor membership of this Working Group that reduces the opportunities to address all the shellfish related subjects. Efforts will be made to increase the range of competencies by promoting the WG and by inviting external experts.

1.3 Adoption of agenda

A general discussion was opened by the Chair who commented the Council's final resolution 2F05 and reported on the last meeting of Mariculture Committee in Vigo last year.

The Terms of reference for 2005 (Annex 3) were commented by the group with a view to organising the work. As usual for the WGMASC meetings, it was proposed by the Chair that the tasks could be dealt with in sub-groups, each of them dealing with a term of reference. During plenary sessions, exchanges between the subgroups would allow to share comments and to formally accept the draft report. The agenda was then formally accepted (Annex 2).

1.4 Appointment of Rapporteurs

Volunteers accepted the task to prepare parts of the report during the work in subgroups and to report on the corresponding ToR during plenary session, in order to assist the Chair.

Pauline Kamermans was appointed as ToR A leader and Rapporteur in plenary session, David Fraser was appointed as ToR B leader and Rapporteur in plenary session, and Francis O'Beirn was appointed as ToR C leader and Rapporteur in plenary session.

2 Update the synthesis and prepare a publication on the development of shellfish hatcheries within ICES countries. This will examine the technical infrastructure and methods (water treatment, broodstock conditioning, feeding schedules, etc.) of the different hatcheries, the proportion of cultured animals to wild conspecifics being used as broodstock and the application of genetic tools (e.g., triploids) to develop hatchery strains (ToR A)

2.1 Preliminary remarks and WG comments

During the meeting in 2003 the Working Group prepared a questionnaire to be distributed to shellfish hatcheries within ICES Member Countries. The return relates only to those countries represented in the WG, and only to commercial hatchery production. However the data set is incomplete, despite being designed to protect confidentiality of individual businesses. This is partly due to the reluctance of several hatcheries to provide relevant information.

After some discussion in 2004, the WG agreed to broaden its audience to include regional organizations to which the hatcheries may be part, local, regional or state authority, and competent scientists in this field. It was also clear from the different contacts that a summary report of the questionnaire be sent to all those participating. It has been suggested that the final product of this ToR should be presented as a report of hatcheries in ICES countries, to reveal the trends in production and needs for research and development.

To improve the contacts with hatchery managers, a new form with an improved presentation was prepared in 2004 by a member and scrutinised by the group. It is intended for use under the auspices of both ICES and the scientist's affiliation. A copy is given in Annex 4.

The summary of returns was updated in 2005 and is presented here reporting on the activities and outputs of hatcheries for the years 2003 and 2004, highlighting environmental issues and areas of priority for Research & Development. The data set is incomplete and recommendations have been made to obtain a more complete data set in the future.

2.2 Rationale

Hatcheries are an essential tool for securing spat availability to the industry, and for the dissemination of genetic stability and improvement. There are several reasons why hatcheries exist. These include the need to restock wild fisheries which have been depleted, to satisfy the demand by culturists and shellfish farmers for a consistent, high quality source of seed and to produce organisms that are not normally available (introduced species or specific strains). Over the course of the last 20 years, there has been a dramatic increase in the number and the size of shellfish hatcheries (see Tables 1 and 3).

Initially, most hatchery technology was developed through publicly-funded government laboratories which were later transferred to and developed by private industry. Hatcheries developed in response to three different needs:

- To complement the decline in wild fisheries that could not supply the market with the demand from local and foreign markets (i.e., *Pecten maximus*, France);
- To supply spat for cultivation of a non-indigenous species; and
- To diversify the sources of spat of a species naturally available and collectable; to ensure a more consistent, higher-quality supply of material for culturists to use as well as to produce specific genetic strains.

The percentage of hatchery-produced animals seeded compared to those caught from wild sources is increasing. In France, for example, approximately 15–20% of *Crassostrea gigas* spat are now produced from hatcheries, most of which are triploids.

2.3 Current status

The degree of hatchery technology varies widely among species. The reasons for these differences are driven by market demand for the end product and the consistent availability of wild-collected spat. Species such as mussels (*Mytilus edulis*) are often readily available from natural settlement and therefore, very few hatcheries have produced commercial quantities of mussel seed. However, owing to the vagaries of natural settlement of mussels, in Ireland, the Netherlands and Norway in recent years, there is a perceived need for development of hatchery facilities for that species. Others, such as *C. gigas, Tapes philippinarum, Mercenaria mercenaria, and Argopecten irradians* are routinely produced in hatcheries throughout the world. While hatchery technology is well developed for these species, others such as scallops (*Pecten maximus, Placopecten magellanicus*) and *Ostrea edulis* have proved more difficult to rear on a routine basis.

Currently, detailed information on hatchery production is not readily available within ICES countries and as a result comparisons on gross production, trends and new developments are difficult to provide. As a result, a survey questionnaire was developed to obtain this information and distributes to hatcheries by WG members.

Some of the basic requirements of the design of hatcheries are related to the maintenance of high-quality standards and the implementation of a good biosecurity policy. Hatcheries require high-quality water supply, secure from future developments that may negatively impact it. Facilities should be designed to maintain high standards of hygiene and efficiency in all phases of production (larval rearing, algal production, etc.) with physical separation of those phases and duplication to avoid failures of any one component. A quarantine unit (strict confinement, effluent treatment) is essential in hatcheries using broodstock from non-native origins, from genetically unique forms (tetraploids), and from areas of unknown disease status. Hatcheries require staff trained in mariculture principles through hands-on learning and formal coursework. Because technology is continually advancing, there should be a requirement for on-going training and development.

Shellfish nurseries are a natural extension of the hatchery system to enable successful and cost-effective rearing of juveniles to a suitable growout size. They are usually located in relatively close proximity to the hatchery, but the feasibility of transporting competent larvae, e.g., in moist containers lacking water, has lead to the technology of remote setting. This enables skilled farmers to nurse spat themselves. Nurseries require a high quality, secure water supply in areas of high primary productivity. The nursery should also be sited in areas with a low probability of introduction of pollutants, bio-fouling, pests or diseases. They may ideally be sited in an approved, disease-free area, thus allowing unrestricted movement of stocks. However, nurseries sited in restricted areas may still send their products in identical areas. In addition to a nursery site, some hatcheries will be more vertically integrated with growout (on-growing) facilities that require environmental and biological characteristics similar to the nursery.

2.4 Regulations

Establishment of a shellfish hatchery depends on national or local legislation to ensure that regional development balances with environmental sustainability, and this may vary in different countries. Specific legislation that may affect hatcheries includes classification of waters and approved zonation for disease agents. Both of these can influence the movement of shellfish for production and utilization of areas. In some cases, shellfish hatcheries, because of poor water quality or the presence of disease agents such as *Bonamia ostrea*, can be severely restricted in their development. For example, in Scotland an oyster hatchery was relocated to a more remote location because of lowering water quality standards which affected conditioning of broodstock and hatching of larvae.

Other legislation includes land-use issues where shellfish hatcheries may not be sited in regions zoned for other activities (Readers will find in the revised COP in the Introductions and Transfer of marine organisms detailed information about the risks of transferring species and methods to reduce those risks). These regulations, in conjunction with local land prices (real estate costs), will often make siting of a hatchery difficult. In other areas, hatcheries are more easily established because they occur in remote locations with low population densities. There is often a lack of education and knowledge of these regulations and, as a result, hatchery owners may circumvent these rules. The implementation of Codes of Practice will be important to increase awareness of responsibilities and bring the existing industry into compliance.

2.5 Impacts

Hatchery production, as previously stated, responds to both quantitative and qualitative needs of the shellfish industry, and, therefore, has positive impacts on this sector as well as consumption. These positive impacts will continue to grow as efficient production practices for the cultured species continue to evolve.

Hatcheries which follow operating codes of practice and biosecurity policies will typically have a low impact on the local environment with respect to water quality, and discharges from these hatcheries will generally be of a high standard. In the absence of accepted facility operating standards, there are potential risks that include the uncontrolled growth of pathogens (e.g., *Vibrio* spp.), discharges of antibiotics, chemicals, disease-agents, fouling organisms and genetically modified materials.

The main function of a shellfish hatchery is to produce seed for planting into the natural environment. The two main biological impacts from these activities are flooding the natural populations with potentially less genetically diverse stock and interaction (competition, predation) with other organisms, including conspecifics in the environment. The significance of this impact (genetic diluting) will be related to the proportion of cultured seed and origin of parent broodstock, in relation to wild stocks in a particular area.

Although the goal of producing cultured seed is to create a high quality, vigorous progeny, in reality, because of low numbers of broodstock used in the hatchery and inadequate rearing (culling) techniques, large numbers of poor quality (low fitness or lowered genetic variability compared with wild stocks) juveniles may be released. The long-term impact of this practice could compromise the success of wild populations by diluting the genome and introducing more undesirable traits into the overall population. A monitoring program to assess genetic variability would ensure the development of diversified broodstock.

One solution to this may be the production of sterile triploids as in the case with *C. gigas* in France and *Mytilus galloprovincalis* on the West Coast of the U.S. Currently there are two methods to produce triploid animals. One is via chemical induction and the other is crossing of tetraploids with diploid broodstock. The dangers in the former technique are that less than 100% of the animals produced are triploid while the dangers of the latter technique would be the unintentional release of tetraploids into the marine environment which could potentially interact with natural diploids producing sterile triploids. Obviously, bio security protocols must be strictly enforced in these cases. For example, a negotiated protocol between French hatcheries (in charge of implementing quarantine facilities), the administration and scientists (ploidy surveys on natural stocks) is under discussion at the moment. Another issue with genetic selection is the development of disease-resistant strains. Although these animals may not be susceptible to local pathogens, they could act as a reservoir and pass the disease on to wild populations[1]. The wild populations should be considered as a valuable source of genetic material (gene bank) and as such, adequately protected.

When introducing non-indigenous species, adverse ecological impacts would involve direct competition for space and food with wild stocks and increasing the number of species interactions. By adding a potentially large biomass of filter-feeding organisms to the environment, some resources may become depleted and limiting to other species. The degree of this impact will be related directly to the volume of the system and its relative productivity. The addition of cultured organisms usually changes the population size of shellfish predators. Depending on stocking densities and on the scale of this response, predation rates on natural populations may either increase or decrease. For example, the increase of cultured seed may deflect some predation from the wild stocks due to their relative proportion or simply encourage an increase in the population of predators by providing an increase in the supply of food. Another potential impact is the intentional introduction of an exotic species to an area through hatchery cultivation (e.g., *T. philippinarum* in France). Unintentional introductions are more numerous and have often arrived at a location with broodstock or juveniles (i.e., *Carcinus maenas*, *Urosalpinx cinerea*, MSX, *Crepidula fornicata*, etc.). The danger of these introductions is that the spread of new species is often unrestricted due to the lack of local biotic and abiotic controls. This highlights the need for a quarantine facility.

Although the risks of culturing unwanted organisms are relatively low in the hatchery environment due to a higher level of control, movement of cultured seed from nursery to growout areas may result in the spread of pests and diseases within and between countries (e.g., *Polydora* infestation of *C. gigas* and *P. maximus* in Scotland). Current legislation encourages trade between EU member states and, unless good legislation and high standards of biosecurity are employed, such pests and diseases are likely to spread.

2.6 Summary of data collected

As part of an ICES working group Terms of Reference on marine shellfish culture, data was sought on the production and development of shellfish hatcheries within ICES countries. To achieve a comprehensive overview of existing expertise and technology, the group consider it important to expand the survey to other parts of the world where species of interest for ICES members are cultured in hatcheries, such as the Mediterranean. Data are presented mainly as anonymous tables. Some are incomplete, since some hatcheries are reluctant to give sufficient information.

---

1 This issue should be discussed together with ICES working groups : WGAGFM and WGPDMO, respectively

2.6.1 Number of commercial shellfish hatcheries

Table 1: Number of commercial shellfish hatcheries[1].

YEAR	2003	2004
Canada	4	n/a
United States	49	n/a
Ireland	6	6
United kingdom	4	4
Norway	1	2
Netherland	0	0
Denmark	1	1
France	6	10
Spain	5	11
Croatia	n/a	0
Greece	n/a	0
Italy	n/a	3
Norway	n/a	2
Portugal	n/a	0
Turkey	n/a	2
Slovania	n/a	2

[1] The table does not include experimental hatcheries, but does include public hatcheries producing commercial quantities of shellfish.

2.6.2 Species reared in shellfish hatcheries

Table 2: Species reared in 2003/2004 in shellfish hatcheries. These are commercially-produced species in the ICES area. The Netherlands, Belgium, Germany, and Poland do not have any commercial shellfish hatcheries. No information was available about Latvia, Lithuania, Estonia, Sweden, Portugal, Finland, and Iceland at this time. The UK hatcheries also include those in the Channel Islands.

SPECIES	CANADA	UK	IRELAND	USA	DENMARK	FRANCE	NORWAY	SPAIN	ITALY	NORWAY
Placopecten magellanicus	X			X						
Argopecten irradians concentricus	X			X						
Mya arenaria	X			X						
Mercenaria mercenaria (notata)	X	X		X						
Ostrea edulis	X	X	X	X	X	X	X	X		X
Crassostrea virginica	X			X						
Chlamys islandicus	X									
Spisula solidissima				X						
Ensis directus	X									
Mactromeris polynema	X			X						
Pecten maximus		X	X			X	X	X		X
Pecten jacobeus						X				
Crassostrea gigas		X	X			X		X		
Tapes philippinarum		X	X			X		X	X	
Tapes decussatus		X	X					X	X	
Venerupis pullastra								X		
Venerupis rhomboides								X		
Haliotis tuberculata			X			X				
Haliotis discus hannai			X							
Donax trunculus								X		

2.6.3 Hatchery production

Table 3: Estimated annual (2003, 2004) shellfish hatchery production (in millions)[1].

Species	Canada	UK	Ireland	US	Denmark	France	Spain
Placopecten magellanicus	5, n/a			n/a			
Argopecten irradians concentricus	n/a			n/a			
Mya arenaria	n/a			5-10, n/a			
Mercenaria mercenaria (notata)	n/a	n/a		>100, n/a			
Ostrea edulis	n/a	<5, <1	n/a	>25, n/a	0.1, n/a	<1, , n/a	n/a/10-20
Crassostrea virginica	n/a			>100, n/a			
Chlamys islandicus	n/a						
Spisula solidissima				>10, n/a			
Ensis directus	n/a						
Mactromeris polynema	n/a			n/a			
Pecten maximus		<1, <1				10, n/a	n/a, 0
Crassostrea gigas		225, 290	10			800, n/a	n/a, >10
Tapes philippinarum		150, 342	50			100, n/a	n/a, >200
Tapes decussatus		20, 1					n/a, >50
Venerupis pullastra							n/a, >30
Venerupis rhomboides							n/a, 0
Haliotis tuberculata			n/a				
Haliotis discus hannai			n/a				
Donax trunculus							0.8

[1)]Some hatcheries were reluctant to provide production estimates.

2.6.4 Technical facilities

Table 4: Quarantine capacity, water source, and effluent treatment of shellfish hatcheries. For future use of tetraploid broodstock, quarantine facilities will be compulsory in France.

(numbers of hatcheries). n/a = not available.

	QUARANTINE YES / NO	WATER SOURCE FLOW THROUGH / RECIRC	EFFLUENT TREATMENT YES / NO
Canada	Na / 1	1 / n/a	N/a
United States	n/a	n/a	N/a
Ireland	n/a	n/a	N/a
United Kingdom	1 / 3	3 / 1	1 / 3
Denmark	0 / 1	0 / 1	1 / 0
France	n/a	6/0	0/6
Spain	0/7	7/0	3/4

2.6.5 Biotechniques

Table 5: Broodstock origin, selection criteria, conditioning methods, and use of triploids per hatchery.

	BROODSTOCK1 WILD /SELECTED	CONDITIONING YES : NO	TRIPLOIDS YES / NO
Canada	1 / 1	1 / na	1 / 3
United States	n / a	49 / 0	3 / na
Ireland	0 / 6	6 / 0	0 / 6
United Kingdom	3 / 3	4 / 0	1 / 3
Denmark	1 / 0	0 / 1	0 / 1
France	1 / 5	6 / 0	5/ 1
Spain	11 / 0	5 / 2	0 / 11

1) A hatchery may hold both wild and selected broodstock, which means that the numbers within a section may be greater than the number of commercial hatcheries (see above)

2.6.6 Larval rearing and spat settlement techniques[1]

Detailed systems employed and problems encountered during larval rearing and spat settlement.

Rearing systems employed include: Flow-through tank systems; static tank systems with 2–3 day 100% water changes, UV- and Ozone-sterlized water

1 Some hatcheries chose not to respond to this question because they perceived their confidentiality would be compromised.

Larval rearing problems: Low survival rates between day 8–10 for *Ostrea edulis*. *Ostrea edulis* failed to breed under hatchery conditions. This may be due to inappropriate broodstock selection and conditioning leading to low quality of the eggs and larval malformation and resultant low survival; improper interaction of feeding techniques and seawater temperature. Larvae are highly susceptible to Vibriosis from cultured algae. Viruses have been isolated from some shellfish hatcheries. During the larval stage, immediate tank disinfection is the most practical response to such infections. In Europe, and specifically in *Crassostrea gigas*, some hatcheries have detected oyster velar virus disease, OVVD, otherwise known as Blister disease. Toxic events often go undetected in shellfish hatcheries until there is a catastrophic failure. To circumvent such failures, there is a need to develop suitable bioassays to monitor water quality problems and to develop analytical protocols to isolate and identify causal agents allowing remediation.

Spat settlement techniques: PVC plates are used for *Ostrea edulis*. Ground glass and crushed shell are used for substrate for settlement. Settlement may occur onto nylon screening in floating trays. Aminobutyric acid (GABA) is sometimes used to speed up metamorphosis in gigas. For some, water motion is created to stimulate metamorphosis. Remote setting is used in oysters.

Spat settlement **problems**: High individual variation in growth rate. Sea scallop metamorphosis and settlement is highly variable within and between years and between hatcheries.

Table 6: Microalgae used for the production of larvae and/or spat.

SPECIES	CANADA	UK	IRELAND	US	DENMARK	FRANCE	SPAIN
T. iso (*Isochrysis galbana*)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
***Chaetoceros* spp.**	Yes	Yes	Yes	Yes	Yes	Yes	Yes
***Pavlova* spp.c**	Yes	Yes	n/a	Yes	No	Yes	Yes
***Thalassiosira* spp.**	Yes	Yes	n/a	Yes	No	n/a	Yes
***Tetraselmis* spp.**	Yes	Yes	Yes	Yes	Yes	Yes	Yes
***Nannochloropis* spp**	Yes	Yes	n/a	Yes	No	n/a	No
***Rhodomonas* spp.**	Yes	No	n/a	Yes	No	n/a	Yes
***Dunaliella* spp.**	Yes	No	n/a	Yes	No	n/a	No
***Skeletonema* spp.**	n/a	Yes	Yes	Yes	No	Yes	Yes

2.6.7 Destination of products

Table 7: Destination of hatchery-reared molluscs. In some countries hatcheries consider this information confidential, but is available at national authorities.

CANADA	THE SINGLE EAST COAST HATCHERY TO RESPOND TO THE SURVEY FROM NOVA SCOTIA, SHIPS BIVALVE SEED TO NOVA SCOTIA, PRINCE EDWARD ISLAND, AND THE NORTHEASTERN SHORE OF NEW BRUNSWICK.
UK	The four hatcheries to respond to the survey ship bivalve seed within U.K (e.g. from Guernsey to mainland), and to Ireland, South Africa, Namibia, Canada, Spain, Italy, France, Israel.
US	Interstate shipping occurs after disease pathogens have been assessed. Overseas shipments occur, but nospecific data are available at this time.
Ireland	Some abalone have been shipped to Spain and Portugal.
Norway	n/a
Denmark	Oyster seed is shipped within Denmark.
France	*C. gigas* is shipped within France, and to Ireland & New Caledonia. *Ostrea edulis* is exported to Spain.
Spain	Most of the hatchery and nursery production was to satisfy the demand of local farmers. A small amount of *C. gigas* was exported to France.

2.6.8 Research & Development: Issues and concerns

Canada: There is need to improve European oyster stock through broodstock selection. Giant scallop (*Placopecten magellanicus*) culture is promising economically, but to date there is no consistency from year-to-year with larval and juvenile rearing methods. There is a lack of support and consistent funding for hatchery-based research. Water quality – should an international standard be developed? Research on recirculation is needed. Standards should be developed for national or international disease certification for seed.

UK: Broodstock selection program for *C. gigas* to improve stock using scientific methodology. A more diverse brood stock population for both Crassostrea gigas and Ostrea edulis should be maintained in hatcheries, preferably in quarantine. Broodstock selection would be designed to avoid inbreeding, and select for parameters such as growth, disease-resistance, and shape, and care should be taken to avoid loss of important alleles for survival, such as temperature tolerance and disease resistance.

Equipment is needed to measure the success of triploidy. There is a concern that triploids may breed successfully with wild diploids and reduce wild spawning stock. There is a need to improve technology on transfer capacity to identify and explore new nursery methods. There is a need to develop a fast, sensitive and economical technique of diagnosing the presence of existing and novel diseases listed under current legislation as guided by the Office International des Epizooties (OIE). Legislation can hamper trade making the movement of oysters and clams in the current system expensive, time-consuming, and inefficient. Scientific support needed to increase communication among and between countries. Relate commercial needs to R&D. Financial support is needed to develop consistent batches of European oysters and scallops. There is a general need to support and develop innovative hatchery techniques. Staff training to ensure expertise in hatchery techniques should be supported. In small hatcheries there is a lack of knowledge in algal culture techniques.

USA: A concern is legislation that restricts interstate movement of shellfish. Other legislation restricts the areas where seed can be grown. There is a need to:

- develop and improve larval and juvenile rearing techniques for sea scallops and other novel species (including the green sea urchin, Strongylocentrotus droebachiensis);
- develop and improve culture methods for microalgal production (continuous vs. batch vs. micropellets);
- increase funding for both basic and applied research relating to shellfish hatchery production;
- provide research on the specific nutritional requirements of larval and juvenile cultured species.

Denmark: High larval mortality is a barrier to commercial hatchery-production of *Ostrea edulis* spat. To identify this bottleneck a research-project have been conducted on condition (fatty acid content) of reproducing adults and larvae without identify any patterns. The future research will focus on infection of bacteria and vira and will compare survival and disease characteristics of larvae reared in intensive and extensive production systems.

France: Genetics and selection: prior domain, under development, in which a share of tasks must evolve between research, expertise, professionnal sector, individual enterprises. Breeders conditioning: not fully controlled until now. Improvements required from environmental and food management for a better control of initial energy reserves, gamete germination, and the sexual maturation process. Larval rearing: water quality, temperature and food management. The genetic effect of culling the slow growers should be better understood. Phytoplankton production: cost reduction by replacing batch methtod by continuous method (different levels of intensity and control from SeaCAPS method to photo bioreactor method)

Spain: A breeding program to obtain *Ostrea edulis* stocks which are resistant to *Bonamia* is in progress. In relation to that, methods are needed to control the mating in flat oyster (e.g. cryopreservation).

Rearing methods for new species of bivalves (*Donax trunculus*, *Solen marginatus*, *Ensis arcuatus* and *Ensis siliqua*) are also being tested in both hatchery and nursery.

Netherlands: A series of years with low natural mussel spatfall and more stringent regulations for collecting wild spat have lead to an increased demand for mussel spat. Thus, interest in producing mussel spat in a hatchery has developed and the first experimental production is presently carried out. For commercial culturing of this new species more research needed. Once the hatchery technique is established in the Netherlands it can be used for other purposes as well, such as the production of triploid mussels, selecting for *Bonamia* resistance in European oysters and culturing of new species.

When new species are introduced the Code of Practice on the Introductions and Transfers of Marine Organisms should be followed (http://www.ices.dk/reports/general/2004/ICESCOP2004.pdf)

2.7 Future directions

Hatcheries are playing a larger role in the production of juveniles for both intensive and extensive (stock enhancement) aquaculture operations, as they allow a better control on juvenile availability. It is predicted that production requirements will increase significantly for many currently cultured species, either related to declining commercial stocks, or to improvement in cultural traits.

The FAO recently produced a comprehensive manual on hatchery culture of bivalves (Helm *et al.*, 2004). It is a synthesis of the current methodologies for rearing shellfish in a hatchery and nursery. The WG recommends that hatcheries use this useful manual, while taking into account the latest developments in hatchery technology. One of the current trends identified in the manual is the use of flow through culture systems as opposed to batch systems for larvae.

The trends in marine shellfish hatcheries appear to be toward more efficient and automated systems. As scale of production increases, this will result in the creation of more small hatcheries and/or larger facilities. In some countries political and social factors may determine the number and size of hatcheries. E.g. shellfish associations may have their own small hatcheries to ensure control over the seed supply.

There is an overall recognition of the importance of high quality water, well-selected broodstock and appropriate technology to improve production. Broodstock selection presently based on empirical methods should take benefit from the increasing scientific knowledge and expertise available in genetics (genetic markers, heritability of useful traits, selection protocols…). There is also a need for scientific support in the field of broodstock conditioning, nutrition, larval and post-larval pathology, so as to ensure reliability of hatchery productions, and effective gains from genetic improvement.

Hatcheries will likely diversify production toward newer, novel, higher-valued species (e.g., *Haliotis* and *Panope*). There is a need for selection criteria for new species to be reared in hatcheries. These criteria should take into account the expected market and risks of introducing a new species into the environment. Another diversication involves bulk species that are easy to rear at moderate cost and amenable to genetic improvement, (e.g. Pacific oysters and mussels).

Selection processes may lead to lowered genetic variability compared with wild stocks. This will also happen when low numbers of broodstock are used. The long-term impact of this practice is twofold. Firstly, it may lead to inbreading of the hatchery produced population. Secondly, it can have effects on the wild population by diluting the genome. A monitoring program and research to assess and study genetic variability is needed. In addition, exchange programs for broodstock between hatcheries would ensure the development of diversified broodstock, while keeping the desired traits. However, the risk of mixing populations through transfer of broodstock populations among hatcheries and thus lowering the overall diversity should also be kept in mind. Avoiding this is essential for the preservation of wild stocks and the succes of cultivated stocks.

New developments in the field of genetic improvement include polyploidy and molecular genetics. This is also identified by the FAO manual. Production of triploid Pacific oysters is now well established, and is underway for new species such as mussels. The advantage of these infertile shellfish is that they can be marketed during the spawning season, which may last for many months in some countries. In addition, faster growth is expected when energy is not allocated to reproduction. Triploid shellfish should be well monitored and controlled in the field, to assess and minimise possible impact on the wild population. Research on modifying specific genes is still in its infancy.

Cryopreservation of gametes is another new development that may ease the work in hatcheries, since it will eliminate the need to condition broodstock. This is also identified as a future direction by the FAO manual.

2.8 Conclusions

Data on hatchery production of shellfish is important for the ICES countries and international agencies relying on ICES advice. With these data the proportion of hatchery produced shellfish to wild stocks can be estimated in the field. In addition, transfer of shellfish from one region or country to another can be traced. Risks of reduced genetic variability or introduction of non-native species can thus be assessed. Furthermore, new research needs for efficient hatchery production can be identified.

Collecting data on hatcheries is complicated and time consuming. The WG members are not satisfied with the level of information they have collected to date. Part of this is due to the low attendance at the 2005 WGMASC meeting (as a result of budget constraints of a number of members). In addition, members that were present at the meeting had had insufficient time to gather data before coming to the meeting. Collection of data on annual hatchery production should be performed by national organisations and preferably be obligatory.

At present, insufficient data are available for a publication other than the WGMASC report. The WG suggests closing this ToR until more data are available or new trends in shellfish hatcheries deserve to be considered.

2.9 Recommendations

WGMASC suggests ICES to recommend that the collection of data on annual shellfish hatchery production should be implemented at a national level by countries. The questionnaire presented in Annex 4 can be used as a guideline.

WGMASC suggests ICES to recommend that the shellfish hatcheries should use the FAO manual while taking into account the latest developments in hatchery technology.

When a national survey on shellfish hatchery production is installed, WGMASC recommends that WGITMO monitors the implementation of the Code of Practice on the Introductions and Transfers of Marine Organisms for hatchery produced shellfish.

2.10 References

Helm, M.M., Bourne, N., Lovatelli, A. (2004) Hatchery culture of bivalves. A practical manual. FAO Fisheries Technical Paper. No. 471. Rome, FAO. 177 pp.

ICES. 2003. Report of the ICES Working Group on Introductions and Transfers of Marine Organisms, Vancouver, Canada, 26–28 March 2003. ICES CM 2003/ACME:04. 168 pp.

3 Prepare a state of knowledge report comparing and contrasting the standard methods used to measure stress indicators in shellfish and provide a discussion of how they would be used to diagnose incidents of cultured shellfish mortality (ToR B)

3.1 Preliminary remarks and WG comments

An evaluation of the conclusions of the 2004 ToR report, when bio indices were reviewed, led the group to focus on the identification of stress indicators. As the content of the report reflects the experience of the members attending the annual meeting, a state of knowledge report is presented on indicators, to robustly evaluate stress on cultured molluscs. However, not all the aspects of this ToR were addressed as the corresponding competences were not found in the group, which was mainly composed of marine ecologists.

Comments were made on the fact that the corresponding measurements will be performed by scientists, while the results will be used by policy makers, environmental managers and producers (farmers). A general opinion was that the way the information will be used by the industry does matter for the group.

Also the need for intercalibration procedures for the stress indicators was identified, as those indicators will be used in different environments and types of shellfish culture

Some material from the 2005 WGPDMO annual report was send by the chair of WGPDMO and distributed to the members. The WGMASC chair expressed thanks to Thomas Lang for this contribution, which is given in Annex 7

Finally, the group considered maintaining its activities intersessionnally. A member will be contacted by the Chair to act as a ToR leader. This person will be responsible for provoking the exchanges among members and preparing a report to be discussed curing the next annual meeting.

3.2 An acceptable definition of stress

In life, organisms adapt to changing conditions in their environment within an ecosystem. They adapt to normal changes, such as temperature, salinity and oxygen supply, then extreme situations from which the whole population is unlikely to survive, i.e., typically extreme physiological challenge (Akberali and Trueman, 1985). Living in tidal environments or being subject to mechanical actions, such dredging may lead to adverse situations which are considered as stressors (Marin *et al.*, 2005; Smaal *et al.*, 1991) This may partly be explained by genetic variation among individuals, of differing fitness, which prevents a group of animals within a population surviving in adverse conditions (Viarengo and Canesi, 1991), or simply that the population is exposed to conditions out with their physiological competence (Bayne *et al.*, 1985).

3.3 Risk of mortality, warning signs

To monitor, test and predict for a problem a, rank of tests could be employed, e.g. observation, followed by a practical, chemical or molecular test, listing tests by risk analysis, thus identifying priorities. This could include stress testing, by exposing animals to conditions which may invoke a response, e.g. ability to burrow in clams or measure strength of muscle closure in scallops.

These tests may be applied in relation to knowledge of differing environmental conditions, by calibrating conditions to the point of death.

3.4 Stress Indicators

An attempt has been made to identify traits or parameters which describe sub optimal conditions, simple characteristics, observable and by test, prior to deleterious effect (Table 1.)

Reference has been made to the 2005 WGPDMO which considers health indices. The presence or absence of a problem may be revealed by a stress indicator, by observation, monitoring, testing and analysis. Moving from general to specific diagnosis via screening to confirmation may lead to a single or multiple causative agents. It is therefore important to observe certain parameters such as behaviour and physiological condition, empirically measure physiological and test chemical function, and susceptibility to death via challenge. An estimation of mortality levels within a population should also be considered.

An indicator should allow simple fast measurements, analysis of complex processes and test results. These analyses should be useable by and explainable to non specialists, such that they can take action to prevent and limit effect. Early warning of a problem is essential, e.g. applying a fast specific and sensitive test for known parameters. They should be systematic, robust management tools, communicating changes which have the potential to lead to a problem and direct to appropriate action. They may take the form of ranked protocol of practical, chemical and molecular tests, which authorities and industry could take responsibility for developing and promoting their use.

Table 1 lists appropriate observations, a practical test of their impact and their influence on a population, in an attempt to diagnose a potential problem.

Table1: Diagnosis of stress by observation, test, and influence on a population.

Observations of variable	Test a representative sample of the population	Identification of stress factor	Species	Reference	Applicable to carrying capacity?
Muscle strength	dynamometric	general	Scallop sp., clams, oysters	Maguire *et al.*, 1999	Y
Byssus production	Time for vertical realignment, by byssus production or behaviour	Depends on general environmental factors	Mussel sp., scallop sp.	Clarke and McMahon, 1996; Dolmer, 1998; Etoh *et al.*, 1997; Moles and Hale, 2003; Stern and Achituv, 1978	Y
Valve closure	Visual observation or recording of valve gap or time of closure	Food availability, disease agent, environmental factors	All bivalves molluscs	Dolmer, 1998; Higgins, 1980; Jørgensen *et al.*, 1988; Kramer *et al.*, 1989; Loosanoff, 1942; Tyurin, 1991	Y
Mantle recession/ Colouration of mantle, gill condition	Observation, light microscopy, chemical analysis	Disease, pollutant	All bivalves molluscs	Strand *et al.*, 1993	?
Shell condition	Observation of shape, integrity and colour, percussion test	Shell growth, fouling, presence of parasite or their effect, pollutant, environmental factors	All shellfish	McDuffee *et al.*, 1999	N

Table 1, continued.

OBSERVATIONS OF VARIABLE	TEST A REPRESENTATIVE SAMPLE OF THE POPULATION	IDENTIFICATION OF STRESS FACTOR	SPECIES	REFERENCE	APPLI-CABLE TO CARRYING CAPACITY?
Change in meat content	Condition indices from industry	Environmental & ecological factors	All mollusc species	Crosby and Gale, 1990, Gee *et al.*, 1977, Leavitt *et al.*, 1995; Marcus *et al.*, 1989; Molares *et al.*, 1986; Rainer and Mann, 1992.	Y
Mortality	Frequency of recent empty shells, Survival in air, stress on stress	General	All molluscs	Eertmann *et al.*, 1993; Viarengo and Canesi, 1991; Wells and Baldwin, 1995; de Zwaan et al., 1995	Y
Behaviour	Burrowing time or depth	General	In fauna	Fleury *et al.*, 1996; Hulscher, 1973; Maguire et al., 1999	?
Physiology	Scope for growth, cardiac activity	General	All molluscs	Coleman, 1974; Depledge and Andersen, 1990; Smaal and Widdows, 1994	?

Note: This is a general guide to stress indication, where one or more parameters may influence a diagnosis. Physiological condition of animals, such as maturity success, although not stress indicators in themselves, can influence recognition of a problem.

Not all the aspects of the ToR were covered due to the fact that some of the more competent members in this field were not able to attend the meeting.

3.5 Conclusion

In order to use those indicators, a practical system includes both a pragmatic, simple approach assessing general stress indicators and more sophisticated tools.

3.6 Recommendation

The WGMASC recommends that this term of reference should remain active, and be developed for the next meeting. Therefore, intersessional work will be organised under the leadership of David Fraser, with the mandate to stimulate the production of the last point of ToR B, that is “provide a discussion of how (stress indicators) would be used to diagnoses incidents of cultured shellfish mortality”.

3.7 References

Akberali H.B., and Trueman E.R.. 1985. Effects of environmental stress on marine bivalve molluscs. Adv. Mar. Biol., 22: 102–183.

Bayne B.L., Brown D.A., and Burns K., eds. 1985. The effects of stress and pollution on marine animals. Praeger press, New York, XVI–384 p.

Clarke M., and McMahon R.F. 1996. Effects of temperature on byssal thread production by the freshwater mussel, Dreissena polymorpha (Pallas) American Malacological Bulletin, 13: 105–110.

Coleman N. 1974. A review of heart rate in the bivalve molluscs. Oceanography and Marine Biology, Annual Review, 12: 301–313.

Crosby, M.P., and Gale L.D. 1990. A review and evaluation of bivalve condition index methodologies with a suggested standard method. J. Shellfish Res., 9: 233–237.

Depledge, M.H., and Andersen, B.B. 1990. A computer –aided physiological monitoring system for continuous, long term recording of cardiac activity in selected invertebrates. Comp.Biochem.Physiol. B, 96A: 474–477.

Dolmer, P. 1998. The interactions between bed structure of Mytilus edulis L. and the predator Asterias rubens L. J.Exp.Mar.Biol.Ecol., 228: 137–150.

Dolmer, P. 2000. Feeding activity of mussels Mytilus edulis related to near-bed currents and phytoplankton biomass. J. Sea Res., 44: 221–231.

Eertman, R.H.M., Wagenvoort, A.J., Hummel, H., Smaal, A.C.1993. "Survival in air" of the blue mussel Mytilus edulis L. as a sensitive response to pollution-induced environmental stress. J.Exp.Mar.Biol.Ecol., 170: 179–195.

Etoh H., Hageshita, S., and Ina, K. 1997. An improved assay for attachment-promoting substances of the blue mussel, Mytilus edulis galloprovincialis. Journal of Marine Biotechnology, 5(1): 24–26

Fleury, P.G., Mingant C., and Castillo A. 1996. A preliminary study of the behaviour and vitality of reseeded juvenile great scallops, of three sizes in three seasons. Aquaculture International, 4: 325–337.

Gee, J.M., Maddock L., and Davey J.T. 1977. The relationship between infestation by Mytilicola intestinalis, Steuer (Copepoda,Cyclopoidea) and the condition index of Mytilus edulis in southwest England. Journal du Conseil International Pour l'Exploration de la Mer, 37(3): 300–308.

Higgins, P.J. 1980. Effects of food availability on the valves movements and feeding behaviour of juvenile *Crassostrea virginica* (Gmelin). I. valves movements and periodic activity. Journal of Experimental Marine Biology and Ecololy, 45: 229–244.

Hulscher, J.B. 1973. Burying depth and trematode infection in Macoma balthica Neth.J.Sea Res., 19: 52–76

Jørgensen, C.B., Larsen, P.S., Møhlenberg, F., and Riisgård, H.U. 1988. The mussel pump: properties and modelling. Mar.Ecol.Prog.Ser., 45: 205–216.

Kramer, K.J.M., Jenner, H.A., and de Zwart D. 1989. The valve movement response of mussels : a tool in biological monitoring. Hydrobiologia, 188/189: 433–443.

Lawler, I.F., and Aldrich J.C. 1987. Sublethal effects of Bis(Tri-N-Butyltin) Oxide on Crassostrea gigas spat. Marine Pollution Bulletin, 18:274–278.

Leavitt, D.F., Capuzzo J.M., and Lancaster B.A. 1995. What does condition index tell us about softshell clam physiology ? Milford Aquaculture Seminar. J. Shellfish Res., 14: 243.

Loosanoff, V.L. 1942. Shell movements of the edible mussel, Mytilus edulis (L.), in relation to temperature. Ecology, 23: 231–234.

Maguire, J.A., Fleury P.G., and Burnell G.M. 1999. Some methods for quantifying quality in the scallop *Pecten maximus* (L.). Journal of Shellfish Research, 18(1): 59-66.

Maguire J.A., O’Connor D.A., and Burnell, G.M. 1999. An investigation into behavioural indicators of stress in juvenile scallops. Aquaculture International, 7: 169–177.

Marcus, J.M., Scott G.I., and Heizer D.D. 1989. The use of oyster shell thickness and condition index measurements as physiological indicators of no heavy metal pollution around three coastal marinas. J. Shellfish Res., 8(1): 87–94.

Marin, M.G., Moschino V., Meneghetti, F., Ros, L.DA. 2005. Effect of mechanical stress in under-sized clams: a laboratory approach. Aquaculture international, 2005.

McDuffee, L.A., Davidson, T.J., and Ireland, W.P. 1999. Breaking strength and failure energy of *M. edulis* shells. Journal of Shellfish Research, 18: 279.

Molares, J., Pascual C., and Quintana R. 1986. Oyster quality: *Crassostrea gigas* . Evaluation of oyster quality, by condition index and biochemical analysis. Incl. 17 ref., Alimentaria, no. 171: 79–87.

Moles, A., and Hale, N. 2003. Use of physiological responses in Mytilus trossulus as integrative bioindicators of sewage pollution. Marine Pollution Bulletin, 46: 954–958.

Rainer, J.S., and Mann, R. 1992. A comparison of methods for calculating condition index in eastern oysters, Crassostrea virginica (Gmelin). J.Shellfish Res., 11: 55–58.

Smaal, A.C., and Widdows J., 1994. The scope for growth of bivalves as an integrated response parameter in biological monitoring. *In* Biomonitoring of coastal waters and estuaries, 247–267. Ed. by K.J.M. Kramer. CRC Press, Boca Raton.

Smaal, A.C., Wagenvoort A., Hemelraad J., and Akkerman I. 1991. Response to stress of mussels exposed in Dutch tidal waters. Comp. Biochem.Physiol., 100C: 197–200.

Stern S., and Achituv Y. 1978. Effects of temperature and salinity on the metabolism and byssal formation of Brachidontes variabilis Kraus (Bivalvia). Comp. Biochem. Physiol., 59A(1): 101–105.

Strand O., Solberg P.T., Andersen K.K., and Magnesen T. 1993. Salinity tolerance of juvenile scallops (*Pecten maximus L*.) at low temperature. Aquaculture, 115(1/2): 169–179.

Tyurin A.N. 1991. Behavioral reactions of the scallop *Mizuhopecten yessoensis*, and the mussel *Crenomytilus grayanus*, to reduced salinity and oxygen and exposure to synthetic detergents as a subject for biological monitoring. Hydrobiol. J., 27(N4): 13–19.

Viarengo, A., and Canesi, L. 1991. Mussels as biological indicators of pollution. Aquaculture, 1994: 225–243.

Wells, R.M.G., and Baldwin, J. 1995. A comparison of metabolic stress during air exposure in two species of New Zealand abalone, *Haliotis iris* and *Haliotis australis*: Implications for the handling and shipping of live animals. Aquaculture, 134: 361–370.

De Zwaan, A., Cortesi, P., Cattani, O., and Vittozzi L. (ed.) 1995. Resistance of bivalves to anoxia as a response to pollution-induced environmental stress. Sci. Total Environ., 171: 121–125.

4 Assess and provide a critique of the standard methodologies used to measure performance indices as related to examining the carrying capacity of the growing area. This will include a review of the effects of HABS, disease and pollution in relation to the performance and carrying capacity of shellfish culture (ToR C)

4.1 Preliminary remarks and WG comments

The ToR identifies that the group should assess the performance indices as relating to estimating the carrying capacity of an area. However, for completeness sake the group needed to finish the sections relating to the effects of various factors upon shellfish performance. WGMASC 2004 addressed the influence of carrying capacity, predation and fouling upon shellfish performance. This report will take that further and begin to outline some of the influence of harmful algal blooms and diseases (pollution) might have on shellfish performance. This work will be continued intersessionally so that other working groups (WGPDMO and WGHAB) can be consulted as well as drawing upon the relevant expertise in the member states.

Pollution was considered by the group as a very broad topic to deal with. It was felt that the experience within the group was not sufficient to address this subject. Guidance might be provided from ACME, MARC, and other WGs, however, it was felt that this subject could not be addressed by WGMASC.

The information generated from these reviews will then be assessed and a series of performance indicators traditionally used to assess the status of cultured shellfish species will be identified. In addition the carrying capacity of shellfish production is defined and considered in light of the traditional indicators.

Finally, in order to incorporate carrying capacity models to overall marine management strategies a more holistic approach is adapted. This would result in the integration of new data sources (e.g. production statistics) into the any potential modelling/management tool development.

4.2 Harmful Algal Blooms (HAB)

4.2.1 Introduction

When considering the effects of HAB it is important to note from the onset, that algal blooms are predominantly naturally occurring phenomena, but frequency and intensity may be increased. They are typically manifested as red or brown tides, or in the form of toxin producing algae which have direct and indirect impacts on the culture species. The presence of toxic algal blooms (a recent phenomena) can have a significant direct or indirect impact upon shellfish production in EU countries, as a consequence of the need to comply with human health regulatory controls.

Monitoring of toxins in cultured species in EU member states is governed by Directives 91/492/EEC, 91/493/EEC, 2002/225/EC.

4.2.2 Impacts

The impacts of HAB on economic and human health aspects are well documented. The impacts directly on the production of the shellfish species are less well defined. However, some obvious impacts are highlighted below.

Algal Blooms:

- O_2 depression following a crash and stress and direct mortality
- Reduced performance due to gill clogging and increased pseudo-faecal production
- Direct mortality of larval shellfish (Helm *et al.*, 2004)
- Physical covering by mats of shellfish growing areas

Toxin producing algae:

- Suspension of harvest
  - Increase in size and biomass in bay
  - Depleation of phytoplankton
  - Increased export to benthos due to
    - Increased faecal/pseudo-faecal production
    - And in case of rope mussels, increased weight on lines resulting in mussel clumps falling to benthos.
- Direct mortality (Gymnodinium)

4.3 Disease

4.3.1 Introduction

The subject of diseases in shellfish species is a science unto itself. Much has be written and recorded on the occurrence, etiology, pathology and impact on performance of shellfish species, both at the species and population levels.

4.3.2 Impacts (on production related characteristics only)

- Increased mortality - reduced production
- Increased standing stock (due to harvest/movement restrictions) – reduced performance (growth, condition)

It is the goal of the group to further develop these two subject areas intersessionally by requesting the help of other working groups (WGHAB and WGPDMO) to review and collaborate on this issue. The final document will be considered at WGMASC 2006 when it is expected that this portion of the ToR will be closed.

4.4 Performance Indicators relating to Carrying Capacity

4.4.1 Introduction

An aspect of this specific term of reference is to identify how shellfish performance indices might relate to estimates of carrying capacity of a particular area. From WGMASC 2004 (review of carrying capacity and the impacts of fouling and predation on shellfish performance) as well as the introduction (above) to the impacts of HAB and disease upon shellfish performance, it is clear that there are many factors (exogenous and endogenous) that can influence the performance of shellfish species in culture. A follow-on effect of this impact is that the carrying capacity of the area in question might be altered. Therefore it is clear that a clear link needs to be made between the performance indicators recorded and a measure of the carrying capacity of the area. There are numerous challenges with this approach and one is defining the exact response of the culture organism to varying levels of the indices (e.g. relating increased fouling to production). In addition, the ability to incorporate these responses into traditional carrying capacity models also present considerable challenges.

However, before attempting to further define the link between carrying capacity and performance indicators, there are a number of guidelines that the working group considered to help direct the review:

1) There is a need to specifically define 'carrying capacity', and to this end the group utilised, reviewed and commented upon the WGEIM 2005 (Annex 1) outline on carrying capacity in shellfish culture species as well as the output upon carrying capacity contained in the WGMASC 2004 report. An EU-funded project named KEYZONE was also presented to the group by a participant (Pauline Kamermans). This project intends to characterize the carrying capacity of key European coastal zones for commercial production of bivalve shellfish. The research is designed to produce powerful tools which would enable shellfish producers in the targeted areas to optimise production capacity, recruitment of young stock, and quality whilst reducing waste (Annex 6).

2) It was the view of the working group that, while it would consider all performance indicators responding to a variety of stressors (e.g., predation, disease, HAB, fouling, etc.), it acknowledges that some indicators might have more value than others. This is due to the fact that they may provide large quantities of spatially and temporally disparate information. Such indicators typically would be utilised by the industry members (and are easily acquired). It was felt that specific attempts should be made to incorporate these into existing or future modelling endeavours.

3) New holistic approaches to integrating different sources of information (e.g. using GIS) and managing ecosystems would be reviewed in order to assess their utility toward determining constraints towards shellfish production and hence, carrying capacity.

4.4.2 Defining the Carrying Capacity

Numerous reviews have dealt with the issue of carrying capacity in relation to shellfish culture operations and are summarised in WGMASC 2004 and Annex 1. In short, there appears to be a major emphasis upon the notion of 'production' carrying capacity while the development of other carrying capacity models appears to be restricted and limited. This working group considered the hierarchical scheme relating to carrying capacity for shellfish culture produced by WGEIM 2005 in Annex 1 (Figure 1). The assessment of carrying capacity for progressively higher categories of models, i.e. increasing in complexity, is based on a sound understanding of preceding categories. This hierarchy outlines 4 types of carrying capacity ranging from broad physical to ecological and socially influenced models.

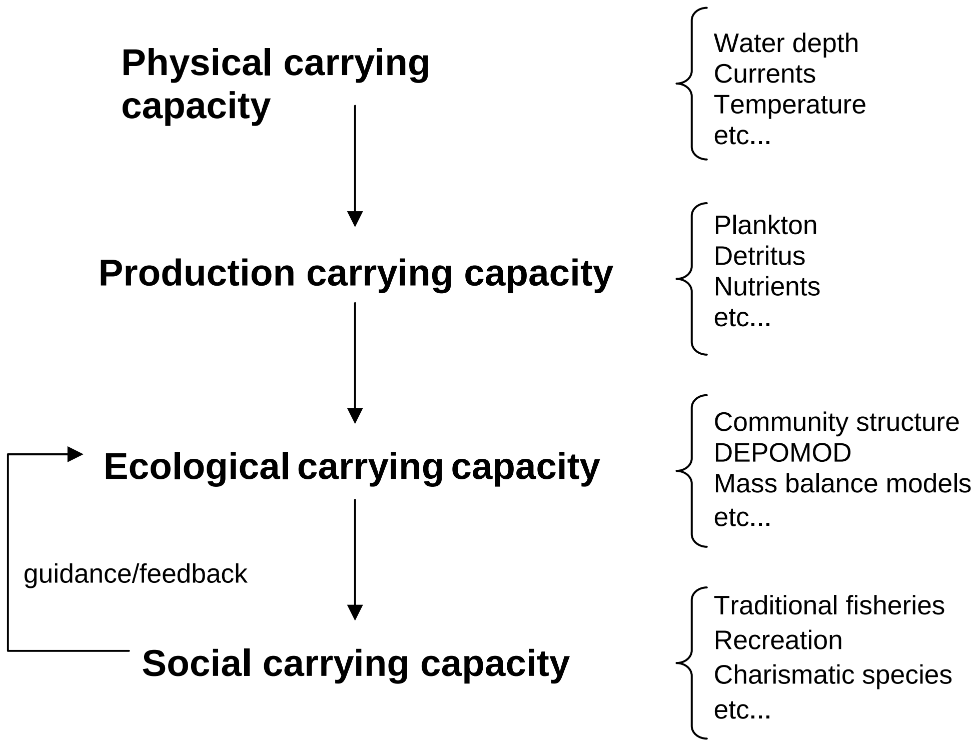

Figure 1: Hierarchical structure to determine carrying capacity of a given area. Note that *social carrying capacity* feeds back directly to *ecological carrying capacity* to provide guidance to choose pertinent response variables to measure (from WGEIM 2005 see Annex 1).

The definitions of the various carrying capacities (after Inglis *et al.*, 2000 and WGEIM 2005-Annex 1) are provided below:

1) *Physical carrying capacity* describes the area that is geographically available and physically adequate for a certain type of aquaculture. It may be assessed by a combination of hydrodynamic models and physical information, presented and analysed within a Geographic Information System (GIS).

2) *Production carrying capacity* has occupied the majority of scientific effort to date. Some of the resulting models have been used successfully to this end. It can be broadly defined as the achievement of optimum production of the target species and is achieved by modifying the stocking density and yield of the target species, in this case filter feeding shellfish. For filter feeding shellfish, it will mainly depend on natural resources and will therefore become interactive the ecosystem (e.g., Carver and Mallet, 1990; Bacher *et al.*, 1998).

3) *Ecological carrying capacity* modelling is still in its infancy and while still relating to the species in culture, it must consider all or certain aspects of the ecosystem. Certain shortcoming relating to these models have been identified by WGEIM 2005 and further development of these models should pay attention to (i) better modelling of feedback mechanisms between shellfish culture and the environment, (ii) a consideration of all steps in the culture process (seed collection, ongrowing, harvesting, and processing), (iii) the type of culture technique employed and (iv) consideration of the interactions between culture activities and sensitive habitats and wild stocks of target species.

4) *Social carrying capacity* provides the context within which the ecological carrying capacity might be calculated. It might be presented as a series of constraint to culture activity (conservation status) or specifically limit the proportion of food (phytoplankton) available to the culture species.

The level of complexity in developing models varies as the number of interacting components increase. For example, primary production and physical models are straightforward (basic models- water exchange, filtration rates, etc.). Secondary production models become more complicated, whereas global ecosystem levels become extremely complex.

However, it is clear from the Figure 1 above, that physical limitation may come before production and ecological ever become limiting in an area.

4.4.3 WGMASC Comments

True Ecological models tend to be all encompassing and focus on no one category or species (e.g. the broad mass balance and ecosystem approach of Jiang and Gibbs (2004). It is clear that the production models are a subset of ecosystem models in that they focus on one species in particular and might be influenced by a number of different factors. The basic ecological model is that which maintains all ecosystem function and presumably will have production of culture species at it's basic/lowest sustainable level, whereas the feedback from the social carrying capacity may increase the level of culture species production to a full production model where production is maximised at any cost.

It is important to note that spatial and temporal heterogeneity of factors may be a major driver of carrying capacity and introduce considerable variability. Factors such as primary production may be greatly influenced by stock levels. This further highlights the notion that simple models (based upon means) may be too simple. In addition the applicability of models from one area to another may not be easily achieved. The broadscale/synthetic and generic approach may have some value and can be applied on a global scale. However such carrying capacity models may be based upon simple concepts but the means generating them may be quite complex and difficult (e.g., hydrodynamic models).

4.4.4 Performance Indicators

A performance index in the context of aquaculture is a means of assessing the effectiveness of the culture method, location and husbandry on the growth and production of the target species. There are a number of criteria that apply to performance indicators that might apply to all indicators (WGEIM 2005). Some of these criteria area listed below (broadly adapted from WGEIM 2005) and might be relevant to the selection or generation of appropriate fit-for–purpose indicators when considering aquaculture in, and management of, marine ecosystems.

1) Indicators must be of the highest scientific credibility and be accepted only after considerable review of the chosen index.
2) In the development of indicators relating to aquaculture activities it is important to consider them from a managers' perspective.
3) Indicators not only have to be scientifically credible but also simple to measure and cost effective and have practical applicability to the aquaculturist.
4) Indicators might be flexible enough to be adapted to the local environment in which they will be used.
5) The ability of an indicator be accepted by all sectors would be an invaluable tool. It must therefore be able to have relevance to all sectors and detect the linkages between them.

There are a number of performance criteria that might be easily obtained and utilised by the industry. Examples of such quantitative indicators are:

- Growth (individual and population) both should be reported.
- Mortality (during period of production) if available may be useful particularly for contained culture operations (e.g., for protected culture, clams, oyster). However, the statistics may not be easily obtained and assigned to a particular cause as

there are many external factors that may influence the overall production of a species.

- Production time to harvest size – (It is important to note if there is a minimum acceptable size or if there are legally set sizes for the aquaculture product (e.g. oysters in US).
- Yield per production area. This would be need to be standardised in terms of weight, volume and production area for comparability purposes (spatially and temporally).
- Meat content. Consideration must be given to seasonal variability however, for the producer the important statistic might relate to the yield at harvest.
- Condition index – as above with meat content.
- Fouling – abundance or percent cover of fouling organisms might be estimated and related to the location, depth, density and size of culture organisms.
- Predation – does the abundance of predators relate to location, depth, density and size of culture organisms. Estimates of lethal or sub-lethal predation might be useful. Does sub-lethal predation result in poorer performance as measured above.
- Disease - similar to predation questions above.
- HABS – relate statutory monitoring results to production statistics above in this list.

There are a number of points to consider when discussing production statistics:

- Production must be estimated by different ways for example, the classical mistake is production is contributed to by all year classes but is measured by the last/largest (i.e. harvest class).
- The interaction between biomass and biological production is critical and should be clearly defined. There is a need to define clearly what the production is being measured.
- The productivity of a bay must account for the production of all species (including wild culture species) and not just the culture species.
- The importance of measuring and reporting variability cannot be understated. Such variability estimates may be important both spatially and temporally. Estimates of variability may provide considerable information relating to the stability of the system and could have considerable bearing on the potential loadings a system might bear.

4.4.5 Discussion

It is clear that the components of the hierarchical carrying capacity approach outlined above cannot be operated in isolation. With the exception of a theoretical 'true' ecological model which is all-encompassing, other models need boundaries and constraints within which to operate. WGMASC fully appreciate that it is not only factors governing growth and performance of shellfish that may limit the carrying capacity of a system. A list of other potential factors that might impact on carrying capacity is provided in WGEIM 2005 with some listed below. The 'Social carrying capacity' does introduce these boundaries and constraints upon the models and therefore might be considered at the onset of model development, given the impractical nature of carrying out true ecological models. The performance indicators typically used in measurements of shellfish production can be used as the means of estimating the effectiveness of the models. What is unclear is what the relationship between the constraints and these performance indicators might be? In addition, there may other 'non-traditional' information that might have considerable applicability to model development or performance measurement and ultimately to estimates of carrying capacity. Such information might be, *inter alia*:

- meteorological/climatic conditions;
- substrate types/benthic habitats;
- nutrient data;
- phytoplankton abundance (and/or chlorophyll levels);
- growth characteristics;
- standing stock of non-target species;
- wild-spat collection;
- diseases;
- legislative constraints (e.g., Natura 2000 sites).

Managers, regulators and aquaculturists might not typically encounter much of the information listed above and might not appreciate the value of this information.

4.4.6 Future directions

When considering future directions with which to develop carrying capacity and utilise them as important management tools three scenarios present themselves:

1) Continue and generate information to feed into models, i.e., the *status quo*.

2) Integrate production data from producers pragmatic approach allowing production to contribute to the data and to consider positively taking management actions which encompass their own perception of the carrying capacity

3) The use of data management tools might help incorporate broader information sources into the management of marine ecosystems and carrying capacity estimates.

WGMASC has identified an example relating to the third point above. This example may represent an approach by which non-traditional information relating to the system in question might be utilised in order to estimate the impact of aquaculture upon the system or determine the carrying capacity of the culture species.

In Denmark, a production area classification system has been developed in order to ensure an optimal planning of mussel production activities (Dolmer and Geitner, 2004). Available data relevant to management decisions were organised in a GIS. The data is used to classify areas in three area categories: areas not available for mussel production, areas that may be available for some forms of mussel production, and area with fishing activities. Table 1 give the factors of restriction that is mapped in the GIS.

Many challenges are presented by this approach, not the least of which is utilising information that would typically not be easily represented in a GIS (e.g., qualitative information). In addition, the incorporation of existing carrying capacity approaches or models might not be easy carried out. What is clear is that this mechanism presents an opportunity and mechanism with which to assess the interactions of the various parameters.

Experience of other countries under a variety of circumstances world-wide can provide information to feed into this system: a proposed strategy instead of just using models, use experience from others areas, information from producers and not limit yourself to one approach and intercalibrate the approach among the areas.

4.5 Summary/Conclusions

Carrying capacity can be structured in a hierarchical system including physical- production- ecological- and social carrying capacity.

Two potential approaches to estimate carrying capacity, the selection of which might be determined by the availability of pertinent information:

- Traditional approach using deterministic energetic models which tend to be quite specific; and/or
- Traditional Carrying capacity estimates might not have the ability to assess the impacts of many of the constraints upon shellfish production within a system. The development of multi-layered databases relating to the information may present a practical way to determine carrying capacity. Using database management tools and GIS might allow the incorporation of additional information into the development of more holistic models of the ecosystem and an assessment of the response of a variety of performance indicators and carrying capacity estimates to some of the non-traditional factors. The use of statistical relationships (correlations, multivariate analysis) - tend to be useful at this broader scale.

The key will then be to develop methodologies to incorporate both of the outputs from these approaches to management and regulation of the system in question in a manner that is acceptable to all.

Growers potentially present a major source of information (in the form of performance indictors) to developing carrying capacity models. It is incumbent upon scientists to assess the traditional performance indicators for their applicability towards the generation of carrying capacity models. If they are found to be deficient then, are there modifications that might be made to improve applicability, while maintaining utility for the aquaculturist.

4.6 Recommendations

- WGMASC recommend to ICES that a theme session at ICES ASC 2006/7 be dedicated towards recent advances in the assessment of carrying capacity and related management tools used in shellfish culture. This session will be jointly sponsored by WGMASC and WGEIM.
- WGMASC recommend to ICES that a comparative study of different management systems be carried out with a view to identifying and testing the response of indices under different production conditions and management regimes. The goal will be to identify the key indices.
- WGMASC recommends to ICES that the stakeholders should be consulted on the development of carrying capacity models so as to provide valuable input into potential constraints and assessing the value of selected performance indicators. The stakeholders should include industry members/representatives, conservation interests, regulatory representatives, and academia.
- WGMASC recommends to ICES that the HAB and Disease sections be completed intersessionally and approved in 2006 with a view closing this term of reference.

4.7 References

Dolmer, P., Geitner, K. 2004. Integrated Coastal Zone Management of cultures and fishery of mussels in Limfjorden, Denmark. ICES C.M. 2004/V:07. 9 pp.

Inglis, G.J., Hayden, B.J., and Ross, A.H. 2000. An overview of factors affecting the carrying capacity of coastal embayments for mussel culture. Report No. NIWA Client Report: CHC00/69.

5 Any other business

5.1 Sessions at the Annual Science Conference in Aberdeen (Scotland)

Information was given on this subject, with the details of the different sessions. While only a few topics are of direct interest to shellfish scientists this year, participants were encouraged to join the ICES Annual Science Conference.

5.2 Draft resolution for 2006

A draft resolution was prepared (annexe VIII). The interest expressed on interactions between shellfish culture and fishery production of scallops and mussels led to the proposal of a new term of reference for the WGMASC. The subject was improved after the meeting, thanks to exchanges among participants. Should the ICES Council approves this draft resolution, it would be conducted intersessionally, one of the members having agreed to take the corresponding leadership.

5.3 Election of a new Chair

The mandate of the Chair ended this year. An election was organized, but since nobody was willing to candidate for the chairmanship. It was agreed upon that the previous chair would contact members who were unable to attend this meeting to see whether a candidate would merge. If this would not succeed, contacts will be taken with the chair of MCC to organize an interim

5.4 Date and venue of the next meeting

The Working Group on Marine Shellfish Culture [WGMASC] (Chair: Peter Cranford, Canada) will meet at The Marine institute, Galway, Ireland, from 18–20 April 2006, following a kind invitation from Francis O'Beirn.

Annex 1: List of participants

NAMES	ADDRESSE	PHONE	FAX	E-MAIL
Alain Bodoy (Chair)	CREMA IFREMER- Place du Séminaire BP 7 17137 L'Houmeau France	+33-546-500-613	+33-546-500-600	Alain.Bodoy@ifremer.fr
Per Dolmer	Danish institute for Fisheries research –DIFRES Department of Ecology and Aquaculture Kavalergaarden 6 DK-2920 Charlottenlund Denmark	+45 339-63-433	+45 339-63-434	pdo@dfu.min.dk
David Fraser	Fisheries Research Services Marine Laboratory P.O. Box 101 Victoria Road Aberdeen AB11 9DB United Kingdom	01-224-295-620	01-224-295-698	fraserdi@marlab.ac.uk
Jose M. Fuentes	Centro de Investigacións Mariñas (CIMA) Consellería de Pesca e Asuntos Marítimos Xunta de Galicia Apartado 13 36620, Vilanova de Arousa Pontevedra Spain	+34-986-500-155	+34-986-506-788	jfuen@cimacoron.org
Pauline Kamermans	Netherlands Institute for Fisheries Research, Centre for Shellfish Research P.O. Box 77 4400 AB Yerseke The Netherlands	+31-113-672302	+31-113-573477	Pauline.Kamermans@wur.nl
Joseph Mazurie	IFREMER Station de la Trinité 12, rue des résistants BP 86 56470 La Trinité sur mer France	+33-297-301-919	+33-297-301-900	Joseph.Mazurie@ifremer.fr
F. O’Beirn	The Marine Institute Galway Technology Park Ballybrit Galway Ireland	+353-9173-0410	+353-9173-0470	Francis.obeirn@marine.ie

Annex 2: WGMASC agenda

Friday 12 May 2005

9:30 Plenary session:

- General discussion on Terms of Reference, adoption of the agenda

12:00 – 13:00 Lunch

13:00 – 15:15 Plenary session.

15:15 – 15:30 Coffee-break

15:30 – 18:15 Subgroup sessions on ToR a and ToR c

Saturday 13 May 2005

9:00 – 12:30 Sub group sessions on ToR a and ToR c

12:30 – 14:00 Lunch

14:00 – 15:00 Plenary Session:

- Comments on the work from each subgroup

15:00 – 16:15 sub group Session ToR b and particular work

16:15 – 16:45 Coffee Break

16:30 – 18:30 Sub group session on the different ToRs

Sunday 14 May 2005

9:00 – 10:30 Plenary Session:

- Review and adoption of report n ToR A

10:30 – 10:45 Coffee break

10:45 – 12:30 Plenary Session:

- Review and adoption of report on ToR C

12-30 – 14:00 Lunch

14:00 – 17:00 Plenary Session:

- Review and adoption of report on ToR C.
- Adoption of the scientific text of the report

17:30 – 17:45 Coffee Break

17:45 – 19.00 Plenary Session:

- Discussion on new Terms of Reference according to the ICES Integrated Action Plan, proposal for intersessional work and leaders, location of the next meeting
- Election of a new Chair for a three-year mandate
- Any other business: mailing list for the working group, incoming events

19:00 : Meeting Adjournment

Annex 3: Terms of Reference (2004/2F05)

2F05 The **Working Group on Marine Shellfish Culture** [WGMASC] (Chair: A. Bodoy, France) will meet in La Rochelle, France, from 13–15 May 2005 to:

a) update the synthesis and prepare a publication on the development of shellfish hatcheries within ICES countries. This will examine the technical infrastructure and methods (water treatment, broodstock conditioning, feeding schedules, etc.) of the different hatcheries, the proportion of cultured animals to wild conspecifics being used as broodstock and the application of genetic tools (e.g., triploids) to develop hatchery strains;

b) prepare a state of knowledge report comparing and contrasting the standard methods used to measure stress indicators in shellfish and provide a discussion of how they would be used to diagnose incidents of cultured shellfish mortality;

c) assess and provide a critique of the standard methodologies used to estimate shellfish performance indices as related to examining the carrying capacity of the growing area. This will include a review of the effects of HABS, disease and pollution in relation to the performance and carrying capacity of shellfish culture.

WGMASC will report by 1 June 2005 for the attention of the Mariculture and Living Resources Committees and ACME.

Supporting Information

Priority :	WGMASC is of fundamental importance to ICES environmental science and advisory process and addresses specific issues of the ICES Strategic Plan.
Scientific justification and relation to Action Plan:	Action Plan references: a) 1.3, 2.4, 2.5, 2.6, 3.9, 6.3 b) 1.10, 3.10, 3.14, 4.6, 6.3 c) 2.12, 3.11, 4.7 a) Shellfish hatcheries are essential for the genetic improvement of broodstock and for securing adequate quantities of high quality spat (juvenile shellfish) for industry grow-out. There is no centralized information base documenting the use of different species by different countries. Current research identifying broodstock sources, broodstock conditioning (for reproduction) techniques, larval rearing and spat settlement for hatchery-reared species needs to be reviewed, synthesized and documented (in collaboration with WGAGFM). Information will be gathered with a survey of commercial shellfish hatcheries. Participants will also be asked to identify their R&D priorities. WGAGFM will provide supporting documentation and reference material for consideration by WGMASC. b) Shellfish production is based on the use of the natural productivity of coastal waters as a source of food. Shellfish require a clean environment and is, in essence, integrating the environmental conditions of the growing area. Unexplained mortalities have an immediate negative effect on both producers and market share. These can be caused by predation, HAB, diseases, pollution, and water quality or any combination thereof. Stress in animals can be caused by either chronic or acute extrinsic factors that may act to decrease the fitness of the animal or to cause its premature death. Use will be made of the biological effects of contaminants literature that is available within ICES. Chronic factors will often be manifested by changes in the overall health of the animal (i.e., in a stepwise cellular-tissue-organ-physiological levels). Acute factors produce immediate responses that may only show up at the molecular\cellular levels. Therefore, detecting acute effects is usually done with biochemical techniques. Different bio-indices will be reviewed and their usefulness determined: adenylate energy charge (AEC), heat shock proteins, total oxy-radical scavenging capacity (TOSC), glycogen content, metallothioneins (MT), cytochrome P4501A1 activity, DNA damage, total lipids and histology. Work will also be cross-referenced with WGEIM. c) Shellfish production accounts for half of the mariculture production in ICES. As such, issues related to shellfish production, in relation to the environment and technological development of the industry need to be addressed within ICES. The effects of the environmental perturbations on shellfish production are dramatic and sudden. There is a need to identify the causes of potential impacts and their effects on the production of shellfish, in order to establish the requirements for the industry in terms of water quality, ecological perturbations and biological competitors. This should be prepared with the view of establishing Ecological Quality Objectives

	(EcoQOs) regarding the shellfish activity. The information will also be useful for determining the ecological requirements for shellfish production in coastal areas. The Working Group has given priorities to the different impacts : 1- Carrying capacity (Hydrographic factors, Primary productivity, food supply), 2- Predation, 3- fouling, 4- HAB Blooms,5- Disease, 6- Pollution (water quality). The Chair of WGMASC will cross-reference all work with the Chairs of WGEIM and WGHABD
Resources requirements:	None required other than those provided by the host institute.
Participants :	Complete membership nominees from ICES countries and invited participants from shellfish hatcheries
Secretariat facilities :	None required
Financial :	N/A
Linkage to advisory Committee :	ACME
Linkage to other Committees or groups :	MARC, MHC, WGHAB, WGITMO, WGPDMO, WGAGFM
Linkage to other organisations :	European Aquaculture Society, World Aquaculture Society

Annex 4: New model of form proposed for use with hatcheries and representatives within ICES Member Countries

ICES CIEM
International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer

FISHERIES RESEARCH SERVICES

The Fish Health Inspectorate
Fisheries Research Services
Marine Laboratory
PO Box 101
375 Victoria Road
Aberdeen
AB11 9DB

Dear Sir, Dear Madam

ANNUAL RETURN OF SHELLFISH FARM PRODUCTION-2[illegible]

As part of an ICES Working Group on Marine Shellfish Culture, I see[illegible] for a report on Production and Development of Shellfish Hatcheries in the [illegible]

Attached are forms requesting information on your s[illegible] please return completed forms by email to fraserdi@m[illegible]b.ac[illegible]

A national and international summary of return[illegible] be[illegible]ced, [illegible]resented in such a way to maintain confidentiality of i[illegible]

Our aim is to produce a re[illegible] on [illegible]ctivi[illegible]d o[illegible] of hatcheries within ICES countries, which is both usef[illegible] the a[illegible]ltur[illegible]stry, highlighting environmental issues and areas of pr[illegible]

If you have[illegible]rns[illegible]ing the [illegible]of the survey form, please do not hesitate to cont[illegible]956[illegible]

Thank yo[illegible]peration[illegible]

Yours Sincer[illegible]

David Fraser

ICES- QUESTIONAIRE ON THE PRODUCTION AND DEVELOPMENT OF SHELLFISH HATCHERIES

GUIDANCE NOTES

Q1. Please enter the site name and a short description of the site location.

Q2.

a) Please enter the number of full time (FT) and part time/seasonal (PT) staff.

b) Do you have a quarantine facility, if so indicate purpose, e.g. holding broodstock, quarantine of imports

c) Indicate

i. the type of water supply, i.e. estuarine, pump ashore, artificial sea water.

ii. if the water supply is treated prior to use, e.g. filtered, ozone, disinfected.

d) Do you treat effluent water (Y/N), what is used, e.g. filtered, ozone, disinfected.

Q3. Please indicate

e) the number of individuals produced,

f) the stage (spat, larvae, etc),

g) whether the site is a hatchery or a nursery (H/N).

Please also indicate

h) any mortality (estimated annual %),

i) the causes of mortality,

j) any treatments.

Q4. Please enter

k) the country of origin of each broodstock species and indicate whether it is wild stock, hatchery stock, or hybrid,

l) the criteria used for species/strain/origin selection, i.e. disease resistance, fast growth rate, high survival, morphological characteristics.

Please also indicate

m) conditioning method e.g. temperature, chemical,

n) if triploidy is employed (Y/N).

Q5. Please enter larval rearing systems employed (e.g., static, flow-through, conical vs. flat-bottom tanks, high aeration vs. low aeration, etc.), and problems encountered during larval rearing.

Q6. Please enter techniques and problems encountered during spat settlement.

Q7. Which microalgal species are used to first feed and ongrow larvae and spat and how you produce your cultured algae (batch, continuous, other).

Q8. Please indicate the destination of spat, please name country of destination

Q9. Please highlight any Research & Development concern, issues or requirements on the reverse on the form.

IN CONFIDENCE

ICES- Working Group on Marine Shellfish Culture

NationalFisheries Research Services

QUESTIONAIRE ON THE PRODUCTION AND DEVELOPMENT

OF SHELLFISH HATCHERIES

1. IDENTITY OF HATCHERY/NURSERY

SITE NAME	SITE LOCATION	

2. HATCHERY INFRASTRUCTURE

NO. EMPLOYEES	QUARANTINE FAC.	WATER SUPPLY	WATER TREATMENT	EFFLUENT TREATMENT
FT- PT-				

3. SPECIES PRODUCED - Estimated production for 2004

SPECIES	NUMBER	STAGE	HATCHERY OR NURSERY	% MORTALITY	CAUSE OF MORTALITY	TREATMENT
Mussels- *M. edulis*						
Pacific oysters- *C. gigas*						
Native oysters- *O. edulis*						
Scallops- *P. maximus*						
Queens- *C. opercularis*						
Venus clams- *M. mercenaria*						
Short-necked clam- *P. phitillinarum*						
Calico clam- ***R.*** *decussatus*						
Other- Specify						

4. BROODSTOCK

SPECIES	ORIGIN	SELECTION CRITERIA	CONDITIONING METHOD	TRIPLOID
Mussels- *M. edulis*				
Pacific oysters- *C. gigas*				
Native oysters- *O. edulis*				
Scallops- *P. maximus*				
Queens- *C. opercularis*				
Venus clams- *M. mercenaria*				
Short-necked clam- P. phililinarum				
Calico clam- R. decussatus				
Other- Specify				

5. LARVAL REARING

a. Please outline all larval rearing systems employed

b. Please outline any problems encountered during larval rearing

6. SPAT SETTLEMENT

a. Please outline all techniques used for spat settlement

b. Please outline any problems encountered during spat

7. MICROALGAE SPECIES AND REARING TECHNIQUES

Which microalgal species are used to first feed and ongrow larvae? How are microalgae reared?

8. DESTINATION OF SPAT

SPECIES	DESTINATION

9. RESEARCH & DEVELOPMENT CONCERNS/ISSUES/ REQUIREMENTS

Annex 5: Extracts from the 2005 WGEIM report

Review of recent development in carrying capacity models for shellfish and recommendations for future directions.

Summary

Models and tools for assessing the carrying capacity of an area of interest for shellfish culture can be classified according to their level of complexity and scope. In this report, we discuss and outline four hierarchical categories of carrying capacity studies as suggested by Inglis *et al.* (2000): *physical*, *production*, *ecological*, and *social carrying capacity*. The assessment of carrying capacity for progressively higher categories of models is based on a sound understanding of preceding categories. We discuss each in brief and the third in more detail as this is the level at which we suggest knowledge is the most lacking and for which science may make the most advances.

(1) *Physical carrying capacity* may be assessed by a combination of hydrodynamic models and physical information, presented and analysed within a Geographic Information System (GIS). (2) Most scientific effort to date has been directed towards modelling *production carrying capacity* and some of the resulting models have been used successfully to this end. We suggest that further development of these models should pay attention to (i) better modelling of feedback mechanisms between shellfish culture and the environment, (ii) a consideration of all steps in the culture process (seed collection, ongrowing, harvesting, and processing), and (iii) the type of culture technique. (3) The modelling of *ecological carrying capacity* is still in its infancy. The shortcomings mentioned for models for category 2 carrying capacity estimatesare even greater for models in this third category. We suggest that GIS be employed to consider interactions between culture activities and sensitive habitats. (4) Regarding *social carrying capacity*, the present WGEIM has nothing to add to the recommendations of the 1998 and 1999 WGEIM reports that reviewed the decision support system SIMCOAST. It is further recommended that this last category be calculated only after the preceding levels have been completed so that an unbiased assessment is obtained. This however does not exclude direction from managers (category 4 models) for scientists as to which factors (such as water clarity, specific habitats, etc.) should be evaluated in the third category. It should be the task of the scientists to develop the response scenarios for various indicators for different levels of production and the task of managers to decide which levels are acceptable for the society based on an evaluation of the results from categories 1 through 3.

Introduction

One of the most contentious issues with respect to the development of mariculture throughout the world is the concept of "carrying capacity". Debate on this concept is often fuelled by the lack of a clear and concise definition of the term which can be interpreted on a wide scale of values that include physical, biological, economic, and social parameters. Thus, for the purpose of this discussion on carrying capacity for shellfish mariculture, we will adopt the definitions of Inglis *et al.* (2000) who divide carrying capacity into four functional categories:

i) *Physical Carrying Capacity* - the total area of marine farms that can be accommodated in the available physical space,

ii) *Production Carrying Capacity* - the stocking density of bivalves at which harvests are maximized,

iii) *Ecological Carrying Capacity* - the stocking or farm density which causes unacceptable ecological impacts, iv) *Social Carrying Capacity* - the level of farm development that causes unacceptable social impacts.

The objectives of this paper are to 1) give an overview of these four different categories of carrying capacity without redoing the work that has been done elsewhere, 2) give a more in-depth review and list the factors that could be considered for category iii as this category is the least developed in terms of predictive power, 3) outline a decision framework for incorporating all four categories into the determination of the overall carrying capacity of a given area for bivalve culture, and 4) outline research to address knowledge gaps for *ecological carrying capacity* studies.

1. Overview of "Carrying Capacity" categories

Physical Carrying Capacity

The concept of *physical carrying capacity* describes the area which is geographically available and physically adequate for a certain type of aquaculture. It depends on the overlap between the physical requirements of the target species and the physical properties of the area of interest (e.g. type of substrate, depth, hydrodynamics, temperature). Physical properties should also include some basic chemical parameters (e.g. salinity, dissolved oxygen concentration) but not biological or organo-chemical parameters (e.g. particulate organic carbon or chlorophyll concentration), which are addressed when calculating *production* and *ecological carrying capacity*. The *physical carrying capacity* of an area also depends on the culture technique, e.g. areas which are adequate for suspension culture may not be for bottom culture and *vice versa* (due to bathymetric or hydrodynamic constraints).

The concept of *physical carrying capacity* is straight-forward without feedback from the aquaculture activity. It may be best addressed using hydrographical models to assess areas of interest based on their physical properties and the physical (culture type) and biological requirements of the species of interest. The pertinent data is then analysed using Geographic Information Systems (GIS) (Congleton *et al.*, 1999; Arnold *et al.*, 2000; Nath *et al.*, 2000; Pérez *et al.*, 2002).

Production Carrying Capacity

The *production carrying capacity* is the optimum production by maximizing the stocking density and yield of the target species, in our case filter feeding shellfish. In the case if filter feeding shellfish, it will mainly depend on natural resources and will therefore becomne interactive the ecosystem (e.g., Carver and Mallet, 1990; Bacher *et al.*, 1998). *Production carrying capacity* may be measured, *inter alia*, in terms of wet or dry weight, energy or organic carbon. It greatly depends on the *physical carrying capacity* and the functions of the ecosystem, especially primary production within the area of interest and, often of even more importance, the importation of organic matter. Furthermore, positive and negative feedback mechanisms between the culture activities and the ecosystem need to be considered.

Several reviews have already been done on this subject, including a series of papers published in a special issues of Aquatic Ecology (volume 31(4), 1998) and the Journal of Experimental Marine Biology and Ecology (volume 219(1-2), 1998), a scoping study in Great Britain (Davies and McLeod, 2003) and an overview in New Zealand (Inglis *et al.*, 2000). The sum of these reviews shows that although there is a wide range of modelling approaches, they focus mainly on food availability and production, bivalve feeding and physiology and the influence of husbandry practices on crop production, as well as the interactions among these factors. The recent review by Kaiser and Beadmen (2002) on production carrying capacity along with the more recent developments in this field as discussed in this text suggest that, for most commercial shellfish species, the ability to assess and predict the effect of stocking densities of bivalves on their production is well developed and has been applied in a wide range of ecosystems. The main constraint of these models is in their limited ability to determine feedback mechanisms, i.e. the effect of the ecosystem response on their activity. A further shortcoming on this category of modelling is that it is usually limited to the ongrowing phase and does not address the seed collection, harvesting, and processing phases. Finally, production carrying capacity may also depend on the culture technique (e.g. bottom versus suspended culture) and the geographical distribution of the culture sites in the area of interest. Although these are critical aspects, that should be investigated and developed, they will be addressed more efficiently in the following section on ecological carrying capacity.

Ecological Carrying Capacity

While modelling of *production carrying capacity* focuses on the target shellfish species and on factors that are directly linked to its production, modelling of *ecological carrying capacity* must theoretically consider the whole ecosystem. Practically, the society or their representatives must restrict this task by defining components of interests (e.g., species or habitats) and acceptable levels of change for each of these (i.e., *social carrying capacity*). *Ecological carrying capacity* will typically be quantified in terms of production of shellfish but needs to include limiting factors such as seed availability and the total usable area.

In comparison with *production carrying capacity*, there have been fewer efforts and successes in developing models to assess and predict the *ecological carrying capacity* of areas for bivalve culture. Also, as for *production carrying capacity*, the few attempts to develop modelling capacity in this field have been limited to the ongrowing phase of cultivation without considering all aspects of the operations and more importantly the interactions with other activities from an integration perspective.

Social Carrying Capacity

The *social carrying capacity* is to some extent even more complex than the *ecological carrying capacity*. It relies on the output from the previous three categories of carrying capacity analysis and aims at developing a comprehensive integrated management strategy based on tradeoffs between all stakeholders to maximize benefits in order to meet the demands of both the population (socioeconomic factors such as traditional fisheries, employment and recreational use) and the environment (Dolmer and Frandsen, 2002; Hoagland *et al.*, 2003; Stead *et al.*, 2003). The WGEIM (1998, 1999) has already reviewed the decision support system SIMCOAST and at present has nothing new to add to the recommendations given at that time. Development of this category is at the heart of Integrated Coastal Zone Management (ICZM) and it must be fully developed so that responsible management decision may be made (Kaiser and Stead 2003).

2. Review of Ecological Carrying Capacity

The concept of ecological carrying capacity is often driven by the public perception of negative environmental effects of aquaculture (Stickney, 2003), which is mostly based on finfish operations. This is partly because aquaculture, especially the culture of carnivorous fish species in netpens, commonly produces strong organic gradients leading away from culture sites (Cromey *et al.*, 2000). This results from the fact that aquaculture operations, especially those in open water net farms, are leaky systems with a considerable proportion of the material added to grow the animals of interest ending up in the surrounding environment (Schendel *et al.*, 2004). This addition of organic matter basically swamps the assimilative capacity of the local environment, thus sometimes changing the physical, chemical, and biological structure of the bottom. However, strong gradients are not limited to fish cage farms and increasing evidence shows that the culture (grow-out) of bivalves may also have considerable influences on the benthic environment (Kaiser *et al.*, 1998). In short, bivalves growing in suspension feed on detritus, phyto- and zooplankton in the water column, using part of what is filtered for growth and consolidating the remaining fraction as either faeces or pseudofaeces, which sinks relatively quickly to the bottom, potentially increasing the accumulation of organic material in the vicinity of the site. For both types of aquaculture, the "footprint" or areal size of the impact is a function of many factors, including the size and age of the farm, the species being cultivated, and local hydrodynamic and natural benthic conditions (Black, 2001).

To date, research on the environmental effects of aquaculture has largely focussed on benthic processes as they relate to increased deposition of organic matter (Carroll *et al.*, 2003). Despite the evidence that aquaculture sites may influence local benthic infaunal (i.e., invertebrates in the bottom sediments) communities (i.e. altering their structure), little work has addressed issues about their productivity and sustainability. Similarly, little research has been directed at examining interactions between bivalve aquaculture and the abundance and productivity of large benthic invertebrates, such as crabs and lobster, and fishes (Munday *et al*., 1994). Further, most work to date has concentrated on near-field effects, ignoring far-field effects. Such effects are rarely discussed (but see Davenport *et al.*, 2003). What's more, when they are, often mostly negative effects are considered, largely ignoring potentially positive ones (see, for example, Gibbs, 2004). A more holistic approach is needed to determine the influence of bivalve aquaculture on the environment and the *ecological carrying capacity* of the environment for bivalve culture.

There is much scientific literature showing that the abundance of fish and macroinvertebrates is greater in areas on or immediately surrounding artificial reefs (ARs - structures placed on the bottom of the sea by humans) (Jensen, 2002) and fish aggregation devices (FADs – structures positioned in the water column or at the surface of the water) (Castro *et al.*, 2002), relative to areas distant to them. Aquaculture sites may function in a manner analogous to these structures (Costa-Pierce and Bridger, 2002; Olin, 2002; Davenport *et al.*, 2003). The remainder of this chapter will address interactions with respect to bivalve culture.

There are many examples of how bivalve culture may have a net positive effect on ecosystem functioning. For example, Tenore *et al.* (1982) suggested that intensive mussel aquaculture in the Ria de Arosa, Spain increases the production of fishes there, although there was no direct evidence given. However, other work done in the same area found increased abundances of several fish species in areas with mussel aquaculture (Chesney and Iglesias) and that the diet of numerous fish (Lopez-Jamar *et al.*,1984; Fernandez *et al.*, 1995) and crab (Freire *et al.*, 1990; Freire and Gonzalez-Gurriaran, 1995) species consisted largely of epifauna from mussel lines. This is also consistent with the observation by Nelson (2003) that fishes are much more attracted to fouled FADs than clean ones. Preliminary observations in the Magdalen Islands, Quebec, have also found increased abundances of benthic fishes, crabs, and lobsters in mussel farms, as compared to control locations. The extent to which such increases in abundances of fishes and benthic macroinvertebrates translate into a heightened productivity remains largely unknown.

Several lines of evidence suggest that an increased abundance of several species at mussel aquaculture sites in the Magdalen Islands, Quebec, Canada, may indeed lead to an increased productivity of these species through a complex cascading effect of aquaculture on the local environment. Winter flounder (*Pseudopleuronectes americanus*) is one of the dominant fish species in the lagoons of the Magdalen Islands and seems to most abundant within mussel farms there. This species is particularly susceptible to predation by sand shrimp (*Crangon septemspinosa*), which are ubiquitous in most coastal areas in northeast Canada, including the Magdalen Islands, and this susceptibility is size-dependent (Taylor, 2003). Thus, the faster they grow and attain a size refuge from predation, the greater their contribution to overall productivity. Winter flounder shift their diet with ontogenetic stage, the smallest sizes depending mostly on small polychaetes (Stehlik and Meise, 2000), which often dominate under mussel aquaculture sites because of increased nutrient loads (Mattsson and Lindén, 1983). The latter is also the case in the Magdalen Islands (M. Callier, personal observations). Our observations that only the smallest size classes of winter flounder are more abundant under mussel lines support the model that mussel aquaculture increases the productivity of this species. Both lobster and rock crabs (*Cancer irroratus*) feed opportunistically on a variety of benthic invertebrates, including the mussels that fall from the longlines in the aquaculture sites, the former also feeding on the latter (Sainte-Marie and Chabot, 2002). Our observations in the Magdalen Islands and elsewhere suggest that there is often an abundance of mussels on the bottom from aquaculture sites. Taken together, this suggests that the growth and productivity of both lobster and crabs may also be increased in the vicinity mussel farms.

The production of epibiota (e.g., crabs, sea stars) on the mussel lines and other structures in mussel aquaculture should also be considered in the context of determining the total productivity associated with mussel aquaculture. The biomass and diversity of such epibiota may be substantial (Carbines, 1993; Kilpatrick, 2002; see LeBlanc *et al.*, 2002 for a recent review) and may contribute *considerably* to the total productivity of the site. For example, recent work by Inglis and Gust (2003) suggests that mussel farms in New Zealand may also increase not only the abundance, but also the productivity of sea stars.

In sum, the interactions between aquaculture and the environment are far from simple. Historical understanding of these interactions is limited to near-field effects and only a limited number of these (e.g., impacts on sediments and communities). Ongoing research in Canada (http://www.aquanet.ca/English/research/an4.php) will help address questions relating to ecosystem-level interactions. But these are doubtlessly very complicated and results are forthcoming.

In some sense, models for calculating the *production carrying capacity* will also go some way to determining the *ecological carrying capacity* of an area for bivalve culture as this will tell us at what point some of the most important filter-feeders in the system (i.e., the bivalves in culture) are having a negative feedback on themselves (and presumably other filter-feeders in the environment). Such models vary greatly in complexity from simplified 2-D box models to more complex 3-D finite element models with hydrodynamics driving the model. Typical variables included are nutrients, phytoplankton, zooplankton, the farmed species, and detritus as well as varying levels of complexity of interactions among these components (feedbacks among these variables, temperature-dependent interactions, etc) (Dowd, 2005). More complex models are also being developed to include polyculture (e.g., Duarte *et al.*, 2003; Nunes *et al.*, 2003), suggesting that this approach to develop more complex "ecosystem" models may also be useful for determining the *ecological carrying capacity* of areas. However, such an approach would require a better understanding of the biology of the other species to be included in the models (although useful estimates may be obtainable for related taxa). A promising method of combining biological observations with nonlinear, non-Gaussian ecosystem models using a probabilistic, or Bayesian, approach has been recently suggested to predict bivalve-environment (mussel-plankton-detritus) interactions and *production carrying capacity* for coastal areas (Dowd and Meyer, 2003).

At this time, two main classes of research are being advanced to determine the *ecological carrying capacity* of ecosystems for bivalve culture. The first of these uses the output from a spatially explicit hydrodynamic-dependent particle tracking models to predict (organic) flux from culture sites to the bottom. A quantitative relationship between flux and a benthic community descriptor is developed and then used to predict the influence different levels of bivalve culture on benthic community structure (Henderson *et al*., 2001). Although initially developed for finfish aquaculture, the DEPOMOD program (Cromey *et al.*, 2002) has also been used to this end for mussel aquaculture in Ireland (Chamberlain, 2002), and is also being evaluated in Canada (http://www.dfo-mpo.gc.ca/science/aquaculture/acrdp-pcrda/quebec/Q-03-01-001_e.htm). In Canada, the modelling (and validation) study is being complemented by manipulative studies to show the dose (flux) – response (community type) relationship. Management decisions regarding stocking densities will then be able to be made based on predicted (benthic) environmental outcomes.

There are a number of limitations with this approach, not all of which are unique in a bivalve culture context. First, there are limits with respect to the hydrographic part of the model. DEPOMOD assumes a homogenous flow field, i.e. that currents do not vary spatially throughout the grid. (This stems from the fact that the model was developed to be used as a simple tool to evaluate finfish culture in Scottish fjords for which accurate 3-D hydrodynamic models are typically not available or realistically possible to develop without undo expense and effort.) Although this may be a reasonable assumption for comparatively small areas as encountered for point sources in finfish culture modelling, this is likely not the case for more extensive shellfish culture that may cover several square kilometres. Although the model may handle complex systems (e.g., with islands, changing bathymetry, heterogeneous bottoms, slopes, multiple sites, etc.), it appears to have difficulties with such systems. As for most modelling, the user must have a good understanding of the study area before beginning the modelling work. Second, the resuspension component of the model has not been fully developed for bivalve aquaculture, is assumed to be static throughout the study site and cannot be modified by the user. The resuspension of sedimented material is complex (depends on sediment type, cohesiveness, flocculation, degradation, etc.) and clearly varies both spatially and temporally. Presently, the resuspension module has been validated for Scottish fjords (salmon farms). More studies are required to validate the current default values used in DEPOMOD (i.e. critical erosion threshold, consolidation time, etc.), especially for bivalve culture. Recent work by Tony Walker (Dalhousie University, Canada) and several colleagues is addressing this point. Third, the choice of the benthic community descriptor used in the model. By default, the model uses the infaunal trophic index (ITI) (Word, 1979a, 1979b) and there is some controversy over the validity of this index. Other more recently-developed indices (e.g., Weisberg *et al.*, 1997; Borja *et al.*, 2000; Llansó *et al.*, 2002a, 2002b; Simboura and Zenetos, 2002; Salas *et al.*, 2004; see also WGEIM 2005 report) may be more appropriate and could easily be used in lieu of the ITI, although these too remain to be fully validated. Fourth, the model has yet to be fully validated in many areas under different environmental regimes (see above) so that its applicability may be considered to be general. Further, although this approach may be useful for a suspended culture system, its utility for bottom culture is doubtful and it does not consider other aspects of bivalve aquaculture that may exist, such as dredging for spat and harvesting. Finally, this approach considers only the benthic component and thus its utility in determining the *ecological carrying capacity* for the entire ecosystem within an area is not possible.

The second approach that is being followed to determine *ecological productivity capacity* is the use of mass-balance / food web models. Early conceptual mass-balance models involved examining the influence of bivalve culture as a part of the ecosystem (Tenore *et al.*, 1982) but not as a model to predict *ecological productivity capacity*. More recent work has used ECOPATH (Christensen and Pauly, 1992) in order to determine the trophic functioning of areas that include bivalve culture in Chile (Wolff, 1994), Taiwan (Lin *et al.*, 1999), South Africa (Stenton-Dozey and Shannon, 2000), Brazil (Wolff *et al.*, 2000), and Italy (Brando *et al.*, 2004). These models differ considerably in their complexity (i.e., number of trophic groups considered) and completeness. Predictably, the presence of bivalve culture is typically seen to promote short energy pathways with high trophic efficiency and may contribute considerably to energy cycling in the studied systems. The aim of these works, however, was not to specifically determine the *ecological carrying capacities* of the areas under consideration, although this was at times evaluated (e.g., Wolff, 1994). A recent paper (Jiang and Gibbs, 2005) specifically attempts to determine the carrying capacity of an area in New Zealand for bivalve culture using a mass-balance approach and the ECOPATH model. Interestingly, they found that although the *production carrying capacity* of the area was 310 t yr^{-1}, the *ecological carrying capacity* of the area was only was 65 t yr^{-1}, above which point there would be major changes in energy fluxes within the system's food web. Future work is planned by Jeanie Stenton-Dozey (pers. comm.) to compile an ECOTROPHIC model of the Hauraki Gulf, New Zealand, to develop a sustainable fisheries and aquaculture industry in the region.

As with DEPOMOD, this approach also has limitations. First, the models used are typically steady-state and thus temporal variation in processes may not be included. Second, the mass balance model typically used (ECOPATH) is not spatially explicit. Thus the model may not be used to differentiate between near-field and far-field effects. Third, an understanding of many biological parameters (life history values, interactions, etc.) is sorely lacking. And finally, this method, again, typically only considers the ongrowing phase of the culture, mainly based on plankton depletion and deposition of organic material; other phases need also to be studied and understood. An abridged list of the activities associated with various stages of bivalve culture that should be considered when determining carrying capacity (all types) is given below:

1. seed collection
    a. dredging
        i. disturbance of benthic communities, especially the removal of long-living species
        ii. increase recruitment success and removal of juveniles from wild populations of target species
        iii. collection of non-target species
        iv. suspension of sediments
        v. release of H_2S and reduction of dissolved oxygen in the water due to oxygen-consuming substances, release of nutrients
    b. artificial collectors
        i. removal of juveniles from wild population of target species
        ii. increasing target and no-target species recruitment success
        iii. alteration of the hydrodynamic regime
        iv. acting as FAD
        v. risk of entanglement for large vertebrates (e.g. marine mammals, sea birds, turtles, sharks).
    c. hatcheries
        i. chemical pollution (e.g. pharmaceuticals)
        ii. genetic selection
        iii. spread of diseases
    d. importation
        i. introduction of alien species
        ii. genetic pollution
        iii. spread of diseases
2. ongrowing
    a. effects common to all techniques
        i. organic enrichment of seafloor
        ii. providing reef-like structures
        iii. alteration of hydrodynamic regime (current speed, turbulence)
        iv. food web effects: competition with other filter feeders, increasing recycling speed of nutrients, removal of eggs and larvae of fish and benthic organisms
        v. spawning: larval release from farmed and associated species

      vi. providing food for predators of shellfish
      vii. control of predators and pests
   b. bottom
      i. activities to prepare the culture plots, e.g. dredging for predator removal
      ii. removal of associated organisms by dredging and relaying
      iii. competition for space with wild benthos organisms
      iv. creation of artificial reefs (physical and biological)
   c. water column structures (trestles, poles, rafts, longlines, etc.)
      i. acting as artificial reef or FAD (attraction/displacement or enhancement of animals)
      ii. behavioural disturbances and risk of entanglement of large vertebrates (e.g. marine mammals, sea birds, turtles, sharks).
3. harvesting
   a. effects common to all techniques
      i. alteration of biomass, nutrients
      ii. removal of non-target species
      iii. competition with predators
      iv. scheduling (temporal)
   b. dredging
      i. disturbance of benthos communities, especially removal of long-living species
      ii. suspension of sediments
      iii. release of H_2S and decrease of dissolved oxygen in the water due to oxygen-consuming substances, release of nutrients
   c. collection of off-bottom structures
4. Processing
   a. dumping of by-catch
   b. relaying near auction houses
   c. depurating
   d. dumping of shells
   e. effluents from processing plant

3. Decision framework to evaluate the carrying capacity of an area

We promote a hierarchical approach to determine the carrying capacity of an area for bivalve culture (Figure 1). At the first level, the *physical carrying capacity* of the site is determined based on the available natural conditions and the needs of the operation and bivalves to be cultured. Second, the *production carrying capacity* of the available area will be calculated based on modelling efforts. Third, the *ecological carrying capacity* of the area will be estimated, again with modelling efforts, by evaluating the range of possible outcomes for production estimates varying between none (and/or the current level) and the maximum calculated as the *production carrying capacity* (Figure 2). For example, an ecologists/scientists could use DEPOMOD to predict the spatial extent of dispersion of biodeposits from a proposed aquaculture operation at various stocking densities and configurations and predict how the benthic community would change along potential depositional gradients. Finally, managers would weigh and balance the different scenarios based on the outcomes from each of the preceding calculations of carrying capacity and competing interests and make a decision as to what level of productivity is acceptable – the *social carrying capacity*.

In contrast to *physical* and *production carrying capacity*, both *ecological* and *social carrying capacity* depend on social values. Thus, before being able to determine the *ecological carrying capacity*, the society must define environmental parameters of interest (e.g. bird and fish populations, clarity of the water, eelgrass or specific rare habitats). Ideally, the ecologists/scientists in charge should then be able to select suitable tools from a tool-box (e.g. models, GIS, and comparisons with previous studies) and predict for a range of production levels scenarios regarding these parameters. The society will then have to define the level of change it is willing to accept (i.e. the ecological carrying capacity). Finally, the interests of all stakeholders need to be addressed (e.g. shipping, recreation, tourism, sewage effluents, etc.), ideally within an ICZM plan, in order to assess the *social carrying capacity* of the management area.

It is important to note that output from the first three categories of models outlined above may or may not be available to the managers making socioeconomic-based decisions (i.e., determining the *social carrying capacity*) because of a paucity of scientific support and resources. Thus managers will likely have to rely on instinct, local knowledge, extrapolation from studies done elsewhere, etc. This does not however remove the logic of the hierarchical nature of the decision tree outlined above and the process should be followed using all available information in order to derive an unbiased view of the situation and thus make appropriate management decisions. Failure to follow this process (by, for example, stating out of hand that certain types of development or developments in certain areas are not permitted) will likely result in otherwise feasible bivalve culture installations not being initiated. This is clearly not in the interest of effective and transparent ICZM.

4. Knowledge gaps and research needs for ecological carrying capacity studies

The WGEIM suggests that work should be done on the following subjects as they relate to *ecological carrying capacity* studies:

- Studies must be done to better understand the role of various types of bivalve culture installations (and other steps in bivalve aquaculture) in the environment, with a balanced emphasis on both “negative” and “positive” influences;
- Existing models must be made spatially explicit;
- Temporal variation must be built into existing models;
- Models must be validated in a number of locations to evaluate their generality.

The WGEIM also recommends that a special session on *ecological carrying capacity* for shellfish aquaculture be held with the following objectives:

- Update on recent advances in *ecological carrying capacity* research and use;
- Determine similarities with other food production sectors;
- Prepare a review paper with recommendations on future developments.

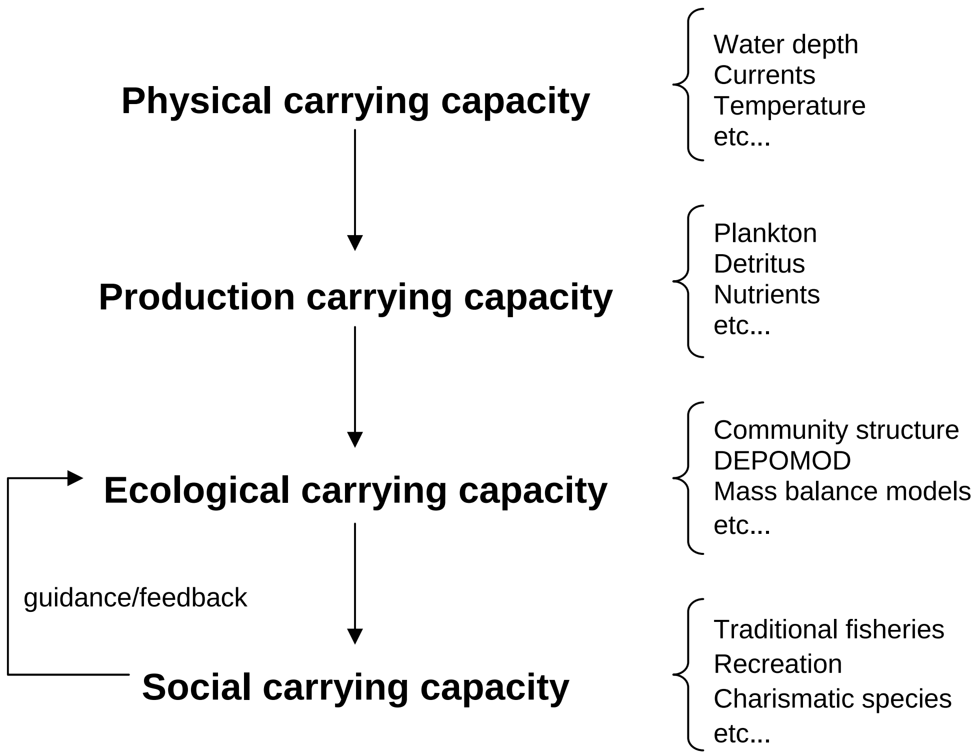

Figure 1. Hierarchical structure to determine carrying capacity of a given area. Note that *social carrying capacity* feeds back directly to *ecological carrying capacity* to provide guidance to choose pertinent response variables to measure.

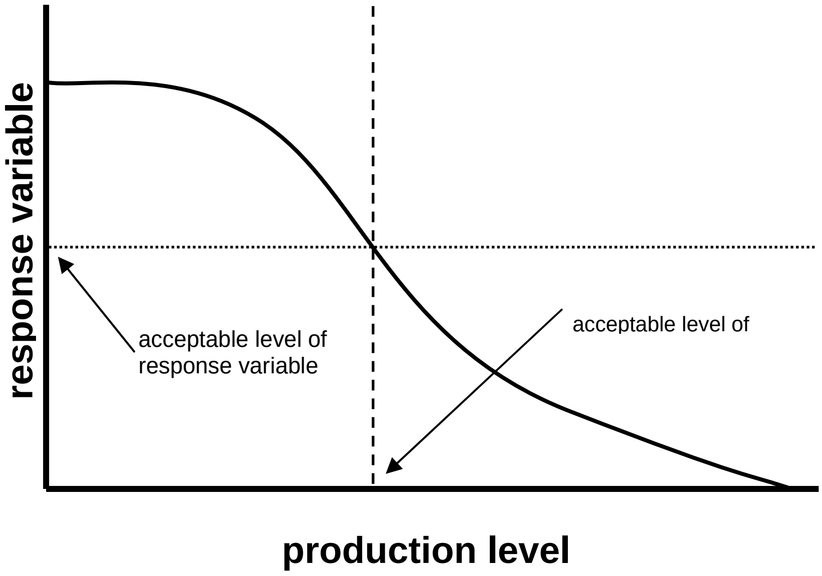

Figure 2. Hypothetical response curve of environmental variable under the influence of varying levels of bivalve culture production. The dotted line indicates the level of the indicator that has been determined to be acceptable by managers and the dashed line the corresponding level of production (i.e., the *social carrying capacity*).

References

Arnold, WS, White, MW, Norris HA, and Berrigan, M.E. 2000. Hard clam (*Mercenaria* spp.) aquaculture in Florida, USA: geographic information system applications to lease site selection. Aquacult Eng., 23: 203–231.

Bacher, C, Duarte, P, Ferreira, J.G., Heral, M.,and Raillard, O. 1998. Assessment and comparison of the Marennes-Oleron Bay (France) and Carlingford Lough (Ireland) carrying capacity with ecosystem models. Aquat Ecol., 31: 379–394.

Black, K.D. 2001. Environmental Impacts of Aquaculture. CRC Press, Boca Raton

Borja, A., Franco, J., Pérez, V. 2000. A marine biotic index to establish the ecological quality of soft-bottom benthos within European estuarine and coastal environments. Mar Poll Bull., 40: 1100–1114.

Brando, V.E., Ceccarelli, R., Libralato, S., and Ravagnan, G. 2004. Assessment of environmental management effects in a shallow water basin using mass-balance models. Ecol Model, 172: 213–232.

Carbines, G.D. 1993. The ecology and early life history of *Notolabrus celidotus* (Pisces: Labridae) around mussel farms in the Marlborough Sounds. MSc thesis, University of Canterbury, Canterbury, NZ, pp. 134

Carroll, M.L., Cochrane, S., Fieler, R., Velvin, R., White, P. 2003. Organic enrichment of sediments from salmon farming in Norway: environmental factors, management practices, and monitoring techniques. Aquaculture, 226: 165–180.

Carver, C.E.A., and Mallet, A.L. 1990. Estimating the carrying capacity of a coastal inlet for mussel culture. Aquaculture, 88: 39–53.

Castro, J.J., Santiago, J.A., and Santana-Ortega, A.T. 2002. A general theory on fish aggregation to floating objects: an alternative to the meeting point hypothesis. Rev Fish Biol Fisheries, 11: 255–277.

Chamberlain, J. 2002. Modelling the environmental impacts of suspended mussel (*Mytilus edulis* L.) farming. PhD thesis, Napier University, pp 200.

Chesney, EJ, Jr., and Iglesias, J. 1979. Seasonal distribution, abundance and diversity of demersal fishes in the inner Ria de Arosa, northwest Spain. Estuar Coast Mar Sci., 8: 227–239.

Christensen, V., and Pauly, D. 1992. ECOPATH II - a software for balancing steady-state ecosystem models and calculating network characteristics. Ecol Model, 61: 169–185.

Congleton, W.R., Pearce, B.R., Parker, M.R., and Beal, B.F. 1999. Mariculture siting: a GIS description of intertidal areas. Ecol Model, 116: 63–75.

Costa-Pierce, B.A., and Bridger, C.J. 2002. The role of marine aquaculture facilities as habitats and ecosystems. Ed. by Stickney RR, and McVey JP. *In* Responsible Marine Aquaculture. CABI Publishing, Wallingford, pp 105–144.

Cromey, C.J., Nickell, T.D., and Black, K.D. 2000. DEPOMOD - Software for predicting deposition of wastes arising from fish farms, pp 10.

Cromey, C.J., Nickell. T.D., Black. K.D. 2002. DEPOMOD - modelling the deposition and biological effects of waste solids from marine cage farms. Aquaculture, 214: 211–239.

Davenport, J., Black, K., Burnell, G., Cross, T., Culloty, S., Ekarante, S., Furness, B., Mulcahy, M., and Thetmeyer, H. 2003. Aquaculture: The Ecological Issues. Blackwell Publishing, Oxford.

Davies, I.M., and McLeod, D. 2003. Scoping study for research into the aquaculture (shellfish) carrying capacity of GB coastal waters.

Dolmer, P., and Frandsen, R.P. 2002. Evaluation of the Danish mussel fishery: suggestions for an ecosystem management approach. Helgol Mar Res, 56: 13–20.

Dowd, M. 2005. A bio-physical coastal ecosystem model for assessing environmental effects of marine bivalve aquaculture. Ecol Model, 183: 323–346.

Dowd, M., and Meyer, R. 2003. A Bayesian approach to the ecosystem inverse problem. Ecol Model, 168: 39–55.

Duarte, P., Meneses, R., Hawkins, A.J.S., Zhu, M., Fang, J., Grant, J. 2003. Mathematical modelling to assess the carrying capacity for multi-species culture within coastal waters. Ecol Model, 168: 109–143.

Fernandez, L., Freire, J.L., Gonzalez-Gurriaran, E. 1995. Diel feeding activity of demersal fishes in the Ria de Arousa (Galicia, NW Spain): An area of intense mussel raft culture. Cah Biol Mar, 36: 141–151.

Freire, J., Fernandez, L., Gonzalez-Gurriaran, E. 1990. Influence of mussel raft culture on the diet of *Liocarcinus arcuatus* (Leach) (Brachyura: Portunidae) in the Ria de Arosa (Galicia, NW Spain). J Shellfish Res, 9: 45–57.

Freire, J, Gonzalez-Gurriaran, E. 1995. Feeding ecology of the velvet swimming crab *Necora puber* in mussel raft areas of the Ria de Arousa (Galicia, NW Spain). Mar Ecol Prog Ser, 119: 139–154.

Gibbs, M.T. 2004. Interactions between bivalve shellfish farms and fishery resources. Aquaculture, 240: 267–296.

Henderson, A., Gamito, S., Karakassis, I., Pederson, P., and Smaal, A. 2001. Use of hydrodynamic and benthic models for managing environmental impacts of marine aquaculture. J Appl Ichthyol, 17: 163–172.

Hoagland, P., Jin, D., Kite-Powell, H. 2003. The optimal allocation of ocean space: aquaculture and wild-harvest fisheries. Mar Res Econom, 18: 129–147.

Inglis, G.J., Gust, and N. 2003. Potential indirect effects of shellfish culture on the reproductive success of benthic predators. J Appl Ecol, 40: 1077–1089.

Inglis, G.J., Hayden, B.J., and Ross, A.H. 2000. An overview of factors affecting the carrying capacity of coastal embayments for mussel culture. National Institute of Water & Atmospheric Research Ltd, Christchurch.

Jensen, A. 2002. Artificial reefs in Europe: perspective and future. ICES Journal of Marine Science, 59: S3-S13.

Jiang, W.M., and Gibbs, MT. 2005. Predicting the carrying capacity of bivalve shellfish culture using a steady, linear food web model. Aquaculture, 244: 171–185.

Kaiser, M., Stead, S.M. 2003. Uncertainties and values in European aquaculture: communication, management and policy issues in times of "changing public perceptions". Aquacult Int 10: 469–490.

Kaiser, M.J., Laing, I., Utting, S.D., and Burnell, G.M. 1998. Environmental impacts of bivalve mariculture. J Shellfish Res, 17: 59–66.

Kilpatrick, B.D. 2002. Assessing habitat value of modified rack and bag aquaculture gear in comparison with submerged aquatic vegetation and a non-vegetated seabed. MSc thesis, University of Rhode Island, pp 157 + xii

LeBlanc, A.R., Landry, T., Miron, G. 2002. Fouling organisms in a mussel cultivation bay: their effect on nutrient uptake and release. Can Tech Rep Fish Aquat Sci #2431:vii+16p

Lin, H.J., Shao, K.T., Kuo, S.R., Hsieh, H.L., Wong, S.L., Chen, I.M., Lo, W.T., and Hung, J.J. 1999. A trophic model of a sandy barrier lagoon at Chiku in southwestern Taiwan. Estuar, Coast Shelf Sci, 48: 575–588.

Llansó, R.J., Scott, D.B., Dauer, D.M., Hyland, J.L., Russell, D.E. 2002a. An estuarine benthic index of biotic integrity for the mid-Atlantic region of the United States. I. Classification of assemblages and habitat definition. Estuaries, 25: 1219–1230.

Llansó, R.J., Scott, D.B., Hyland, J.L., Dauer, D.M., Russell, D.E., Kutz, F.W. 2002b. An estuarine benthic index of biotic integrity for the mid-Atlantic region of the United States. II. Index development. Estuaries, 25: 1231–1242.

Lopez-Jamar, E, Iglesias, J., and Otero, J.J. 1984. Contribution of infauna and mussel-raft epifauna to demersal fish diets. Mar Ecol Prog Ser, 15: 13–18.

Mattsson, J., and Lindén, O. 1983. Benthic macrofauna succession under mussels, *Mytilus edulis* L. (Bivalvia), cultured on hanging long-lines. Sarsia, 68: 97–102.

Munday, B., Eleftiheriou, M., Kentouri, M., and Divanach, P. 1994. Quantitative statistical analysis of the literature concerning the interaction of the environment and aquaculture - identification of gaps and lacks. J Appl Ichthyol, 10: 319–325.

Nath, S.S., Bolte, J.P., Ross, L.G., and Aguilar-Manjarrez, J. 2000. Applications of geographical information systems (GIS) for spatial decision support in aquaculture. Aquacult Eng 23: 233–278.

Nelson, P.A. 2003. Marine fish assemblages associated with fish aggregating devices (FADs): effects of fish removal, FAD size, fouling communities, and prior recruits. Fish Bull, 101: 835–850.

Nunes, J.P., Ferreira, J.G., Gazeau, F., Lencart-Silva, J., Zhang, X.L., Zhu, M.Y., and Fang, J.G. 2003. A model for sustainable management of shellfish polyculture in coastal bays. Aquaculture, 219: 257–277.

Olin, P.G. 2002. Environmental interactions of bivalve shellfish aquaculture. Ed. by J.R. Tomasso. *In* Aquaculture and the environment in the United States. U.S. Aquaculture Society, A Chapter of the World Aquaculture Society, Baton Rouge, pp 141–154.

Pérez, O.M., Telfer, T.C., Beveridge, M.C.M., and Ross, L.G. 2002. Geographical Information Systems (GIS) as a simple tool to aid modelling of particulate waste distribution at marine fish cage sites. Estuar, Coast Shelf Sci, 54: 761–768.

Sainte-Marie, B., and Chabot, D. 2002. Ontogenetic shifts in natural diet during benthic stages of American lobster (*Homarus americanus*), off the Magdalen Islands. Fish Bull, 100: 106–116.

Salas, F., Neto, J.M., Borja, A., Marques, J.C. 2004. Evaluation of the applicability of a marine biotic index to characterize the status of estuarine ecosystems: the case of Mondego estuary (Portugal). Ecol Indicators, 4: 215–225.

Schendel, E.K., Nordstrom, S.E., Lavkulich, L.M. 2004. Floc and sediment properties and their environmental distribution from a marine fish farm. Aquac Research, 35: 483–493.

Simboura, N., and Zenetos, A. 2002. Benthic indicators to use in ecological quality classification of mediterranean soft bottom marine ecosystems, including a new biotic index. Medit Mar Sci 3/2: 77–111.

Stead, S.M., Burnell, G., and Goulletquer, P. 2003. Aquaculture and its role in Integrated Coastal Zone Management. Aquacult Int 10: 447–468.

Stehlik, L.L., and Meise, C.J. 2000. Diet of winter flounder in a New Jersey estuary: ontogenetic change and spatial variation. Estuaries, 23: 381–391.

Stenton-Dozey, J.M.E., Shannon, L.A. 2000. Impact of mariculture on ecosytems: an ECOPATH approach to assess the impact of mussel culture on trophic interactions 1st MARICULT Conference, Trondheim, Norway.

Stickney, R.R. 2003. How did we get into this mess? Junk science vs. real science. World Aquacult, 34: 4–7, 71.

Taylor, D.L. 2003. Size-dependent predation on post-settlement winter flounder *Pseudopleuronectes americanus* by sand shrimp *Crangon septemspinosa*. Mar Ecol Prog Ser, 263: 197–215.

Tenore, K.R., Boyer, L.F., Cal, R.M., Corral, J., Garcia-Fernandez, C., Gonzalez, N., Gonzalez-Gurriaran, E., Hanson, R.B., Iglesias, J., Krom, M., Lopez-Jamar, E., McClain, J., Pamatmat, M.M., Perez, A., Rhoads, D.C., de Santiago, G., Tietjen, J., Westrich, J., Windom, H.L. 1982. Coastal upwelling in the Rias Bajas, NW Spain: Contrasting the benthic regimes of the Rias de Arosa and de Muros. J Mar Res, 40: 701–772.

Weisberg, S.B., Ranasinghe, J.A., Dauer, D.M., Schaffner, L.C., Diaz, R.J., and Frithsen, J.B. 1997. An estuarine benthic index of biotic integrity (B-IBI) for Chesapeake Bay. Estuaries 20: 149–158.

Wolff, M. 1994. A trophic model of Tongoy Bay - a system exposed to suspended scallop culture (Northern Chile). J Exp Mar Biol Ecol, 182: 149–168.

Wolff, M., Koch, V., and Isaac, V. 2000. A trophic flow model of the Caeté Mangrove Estuary (North Brazil) with considerations for the sustainable use of its resources. Estuar, Coast Shelf Sci., 50: 789–803.

Word, J.Q. 1979a. The infaunal index. *In* A relative abundance measure of the benthic infauna and how it may be applied to fish food habits studies. Presented at: 2. Pacific Northwest Technical Workshop, Gutshop '78; Maple Valley, WA (USA); 10 Oct 1978. Ed. by Lipovsky SJ, and Simenstad C.A. pp 37-42

Word, J.Q. 1979b. The infaunal trophic index. In: Bascom W (ed) Southern California Coastal Water Research Project, annual report (1979). SCCWRP, Los Angeles, pp 19–39.

Annex 6: Summary of a project financed by the EU

Project acronym: KEYZONES(R)

Project title:
'To investigate sustainable biological carrying capacities of key European coastal zones'

This project deals with the characterisation of the carrying capacity of key European coastal zones for commercial production of bivalve shellfish. The research is designed to produce powerful tools which would enable shellfish producers in the targeted areas to optimise production capacity, recruitment of young stock, and quality whilst reducing waste. The work will also increase the scope and credibility of generic, ecosystem models - with a consequent application to the wider industry and other stakeholders in coastal zones. The outcomes are designed to fit with integrated coastal zone management schemes throughout Europe.

The research consists of 5 inter-dependent TECHNICAL work packages plus Review & Assessment and Project management:

1) Historical Data Collection: Objectives are the collection and storage of historical data that describe environmental parameters and processes at each culture environment (Loch Creran-UK, Eastern Schedlt - Netherlands and SE Waterford-Ireland), including the physiology and culture practise for each main shellfish species cultured in those environments.

2) Field Work: Objectives are to measure (i) temporal and spatial variations in the environmental parameters that act as forcing functions driving our simulations of shellfish growth and ecosystem processes (e.g. food availability, light, temperature) (ii) physiological responses required to parameterize the generic physiological model for each shellfish species, and (iii) natural shellfish growth and ecosystem variables (e.g. chlorophyll) that will be used to calibrate and validate the models.

3) **Modelling the physiology of cultured species**: Objectives are to (i) develop a dynamic model structure that may be parameterized to simulate feeding, excretion, growth and reproduction in different shellfish species cultivated throughout Europe; (ii) parameterize that generic model structure for separate species to include the mussels Mytilus edulis, and oyster Crassostrea gigas and (iii) validate simulations.

4) Ecosystem scale modelling: Objectives are to describe and predict carrying capacity, using ecological modelling. Ecosystem models with variable spatial resolution will be used, in order to combine hydrodynamics, biogeochemistry and shellfish population dynamics for multi-year simulations. The specific objectives, for each culture environment (Loch Creran UK, Waterford estuary Ireland, Eastern Scheldt Netherlands), are (a) To integrate external forcing from watershed and coast in ecosystem scale models; (b) To simulate the major internal processes responsible for energy flow; and (c) To describe and predict growth for relevant cultivated species, at resolutions that are adequate for fisheries and resource management.

The general modelling approach will be to develop a multi-year ecosystem model of the culture environment, to which individual shellfish growth (WP3) and population dynamics (WP4) will be coupled. Integration will reflect the time and space scale requirements for the different systems and objectives. The models produced will be input to WP5 (mapping) where map-based prototypes will be produced.

5) Mapping for Exploitation: Prototype models will be produced, which will allow the user to investigate various management strategies, for example farm expansion, and will provide an indication of the likely environmental, and economic impacts of these strategies. This management tool will be developed as a commercial deliverable to other SME (and interested parties) through a consortium partner which specialises in such tools (La Tene Maps (6)) .

Critical points are the achievement of: **a)** · To develop tools to meet specific local needs to assess carrying capacity , recruitment, growth potential, stocking densities and yields - within the SME participant group. **b)** · To provide a commercial, and marketable, tool for a wider group of industry and regulators **..c)** · To assist SMEs to reduce waste in, both, effort and financial terms**. d)** Development of a dynamic dataset

PARTIC. ROLE*	PARTIC. TYPE**	PARTIC. NO.	PARTICIPANT NAME	PARTICIPANT SHORT NAME	COUNTRY	DATE ENTER PROJECT***	DATE EXIT PROJECT***
CO	SMEP	1	NorthBay Shellfish Limited	NBS	UK	1	24
CR	SMEP	2	Caledonian Oyster Co Ltd	Caledonian	UK	1	24
CR	SMEP	3	A Cornelisse	ACORN	NL	1	24
CR	SMEP	4	South East Shellfish Co-operative Ltd	SESCO	Ireland	1	24
CR	SMEP	5	Clew bay Marine Forum	CBMF	Ireland	1	24
CR	SMEP	6	La Tene Maps	La Tene	Ireland	1	24
CR	OTH	7	Association of Scottish Shellfish Growers	ASSG	UK	1	24
CR	OTH	8	Cooperatieve Producenten organsiatie voor de Nederlandse Mosselcultuur	P O Mossel	NL	1	24
CR	OTH	9	Cooperatieve Producenten Organisatie Nederlandse Oestercultuur	P Oesters	NL	1	24
CR	RTD	10	Plymouth Marine Laboratory	PML	UK	1	24
CR	RTD	11	Netherlands Institute for Fishery research	RIVO	NL	1	24
CR	RTD	12	Instituto do Mar	IMAR	Portugal	1	24
CR	RTD	13	Scottish Association for Marine Science	SAMS	UK	1	24
CR	RTD	14	Stichting Waterloopkundig Laboratorium	WL Delft	NL	1	24
-	OTH/ SMEP	-	Possibility of Greek or S European SME as end user		Greece/ S Europe	11	24
-	OTH	-	Regulatory Body (s)		?	13	24

Annex 7: Extracts from the 2005 WGPDMO Report and corresponding annexes, for the meeting of WGMASC, 13–15 May 2005

1. Compile information on the distribution, causes and significance of the Summer Mortality in the Pacific oyster (*Crassostrea gigas*) and in other bivalve species

A working document was summarized by T. Renault (Annex 6).

The first part of the document, prepared by S. Ford, provided general information on Summer Mortality syndrome, including information on the bivalve species affected and the geographical distribution. The first description of the Summer Mortality syndrome concerned the Pacific oyster (*C. gigas)* in Japan in the 1940s. The syndrome was, and continues to be, associated with high mortality of Pacific oysters and other bivalves around the world (Japan, USA, Canada, China and France). The causes remain unclear, but a multifactorial aetiology is suspected.

The second part of the document, prepared by T. Renault and J. F. Samain, summarised results of the multidisciplinary MOREST Programme on Pacific oyster Summer Mortality in France. The project focuses on the interactions among environment, oysters and pathogens, and consists of a research network involving genetics, physiology, immunology, pathology, ecotoxicology and ecology. Researchers in each discipline have analysed the same biological material, and have coupled lab and field studies. This approach identified and assigned relative importance to the factors involved.

J. F. Samain (MOREST project director, IFREMER Brest, France) then provided an overview of MOREST programme results:

- A temperature of 19 °C or more is the primary necessary condition, but alone is not sufficient to produce mortalities.
- A genetic component evidenced by divergent selection in two generations was confirmed. Resistant oysters produce fewer gametes and spawn more completely than susceptible ones regardless of food supply.
- High nutrient levels favour reproduction over other metabolic needs and may lead to energetic imbalance.
- Triploids, which have greatly reduced gametogenesis, suffered the lowest mortalities and also demonstrated higher potential defence capacities than diploids.
- A stressor, such as a simple transfer of oysters, was necessary to induce mortality even when temperature and reproduction were favourable. Proximity to the sediment consistently exacerbated the mortalities.
- Herpesvirus (OsHV-1) was mostly detected in juvenile mortality events and when the temperature was high. Different species and strains of Vibrios (including *V. splendidus* and *V. estuarianus*) were also isolated from moribund oysters.

Conclusions

1) Several bivalve species are affected by the Summer Mortality syndrome in different countries. However, most research programmes are focused on the Pacific oyster (*Crassostrea gigas*) because of its worldwide commercial importance.

2) The collective evidence suggests that Summer Mortality involves a suite of intrinsic and extrinsic factors. The most important extrinsic factor seems to be elevated temperature coming at a time when the intrinsic factors gametogenesis and

spawning place the animal in a relatively unstable physiological condition. Any other external factor that exacerbates this instability, including high food availability, physical stressors or pathogens, may push the animals over a threshold from which they cannot recover.

Recommendations

WGPDMO recommends that:

v) investigations continue to study the intrinsic and extrinsic factors associated with Summer Mortality in bivalves, and their interactions, in order to better define their roles in the phenomenon;

vi) coordinated studies be done by ICES Member Countries affected by Summer Mortalities in Pacific oyster (*Crassostrea gigas*) and be extended to other species.

2 Update and assess the current information on the effects of contaminants on the immune system in fish and shellfish

K. Broeg presented a review of the recent literature in the field of immunotoxicological studies (laboratory exposure experiments and field studies) in fish (Annex 7).

The main focus was placed on the innate immune system due to its important role as the first line of defence against pathogens and its evolutionary conservation. In summary, the following aspects were extracted from the reviewed studies:

- Nearly all known ecotoxicants have either stimulating or suppressing effects on innate immunity of fish. All factors of innate immunity might be affected: external factors, humoral internal factors, and cellular internal factors.
- Results obtained were dependent on toxicant doses, exposure time, toxicity of mixtures, methods used, cell type used, origin of the cells, species, gender, temperature, and salinity changes.
- Acute responses to sublethal contaminant concentrations often initiate general stress effects reflected by triggered immune activity, whereas chronic responses might be coupled with cytotoxic effects reflected by immunosuppression.
- Examples were given for effects of immunomodulation on protective actions. Several studies also indicated a potential interaction between reproduction, biotransformation, and immune response in fish.

A review prepared by T. Renault, M. Auffret and B. Gagnaire on recent studies on shellfish is included in Annex 7.

M. Auffret presented the results of some studies conducted on immunosuppressive effects of contaminants in shellfish. He reviewed studies on the potential risk for increased susceptibility to pathogens due to contaminant effects. A scheme recently developed by Luster *et al.* (2005) demonstrated the role of immunotoxic agents and other factors in infectious disease susceptibility.

Alterations of haemocyte numbers and viability and functional modulations (phagocytic capacity/ respiratory burst/ membrane potential) were applied in concert and have been shown to be reliable indicators for toxicity-induced immunomodulation in shellfish in both exposure experiments and field studies. The combined measurement is useful in order to account for the fact that immune parameters may compensate the decrease of others. Thus, the overall resistance may not be compromised by the impairment of a single immune parameter. For future perspectives, studies on host resistance to pathogens, and the derivation of shellfish disease models were suggested.

In the discussion it was emphasised that techniques measuring effects of contaminants on the immune systems of fish and shellfish are a promising tool in ecotoxicology. However, more research and validation is needed before they can be recommended for regular monitoring activities.

Conclusions

- Studies demonstrate an effect of various pollutants on the innate immune system in fish and shellfish.
- The relationship between immunomodulation induced by pollutants and higher susceptibility to infectious diseases is rarely demonstrated.
- Although techniques measuring effects of contaminants on the immune systems of fish and shellfish are considered promising tools in ecotoxicology, more research and validation is needed before they can be recommended for regular monitoring activities.

Recommendations

WGPDMO recommends that:

i) methods in use to explore the innate immune system in fish and shellfish should be harmonised;

ii) a combined approach including methods (functional and structural) on different factors of innate and acquired immunity should be used to obtain broader information about immunological disorders;

iii) information about the effects of immunomodulation caused by contaminants on disease susceptibility in fish and shellfish should be compiled.

3 Provide guidance on the applicability of the various available 'health indices' for the interpretation of data obtained from biological effects monitoring activities and associated research studies using pathology and disease endpoints

W. Wosniok presented a summary of a working document, providing a review of indices in use in the field of biological effects studies (Annex 8).

The purpose of a "health index" in the present context is to summarise information on the health status of marine organisms. While the original information on health status is expressed by several (many) quantities, an index is expected to represent the most relevant information by one (or at least few) number(s) or category(ies). Such an index should facilitate the interpretation of measurements as well as communication about health status based on a broad range of information. Monitoring results could be presented in a concise way via such an index. An index could also be the target quantity on the basis of which spatial comparisons and trend assessments could be performed.

Index components must exhibit a monotone (only up or only down, not variable) relationship between exposure and response and this relationship must be biologically plausible (to prevent coincidental correlations from contributing to the index). The set of components contributing to the index should provide a proper summary of the measurements, which the index is to represent. This issue must clearly be defined to allow a sensible index construction. Finally, the index definition should be so detailed that subjective decisions about its calculation are avoided.

There is a wealth of possibilities to calculate a summarising index. The simplest and most frequently used way is to calculate a weighted sum of the original components, where necessary, after standardising components to non-negative values with a common dispersion and orientation for all components. However, arguments to define the weights are subject for discussion.

In the six examples discussed in some detail in the working document, weights are set on the basis of various arguments, ranging from “set all weights to 1, because other choices are difficult to justify” to explicitly given variable weights which were felt optimal by the authors. In other cases the weights are obtained by rescaling the data in terms of a “normal range” or a background value.

The Integrated Biomarker Response (IBR) uses a different approach by arranging standardised index components in a star plot and using the star plot area as the IBR index value. This index is not a weighted sum of component values with fixed weights; instead the index is a sum of products of the component pairs in the star. This makes the IBR value depend on the order of the radii in the star, which is rarely naturally given, but instead depends on the more or less random preference of the user and thus introduces a high degree of subjectivity and randomness in this index. Another undesirable feature is that a component contributes only in cooperation with its neighbours in the star, which means that if these neighbours are equal or close to zero, then the middle component will contribute little or nothing to the IBR, however large its values. Summarising, the IBR might only be useful under few circumstances.

Besides defining an index as a sum of weighted component values by fixing weights on the basis of external consideration, another way is to derive these weights formally such that the resulting index carries as much as possible of the information in the set of the original components. Principal component analysis (PCA) is a standard technique for this purpose and other multivariate techniques may similarly be applied if the purpose of the index is, for instance to highlight the differences between groups in the data. The use of these methods obviously provides an elegant solution to the question of how to derive weights for a given data situation. However, the optimality holds only for the data set under study, which means that new data would require new optimal weights. On the other hand, if a summarising quantity for only a certain data set is required, PCA and related methods are reasonable instruments to generate an index.

In summary, none of the investigated indices described the disease-related parameters of interest for the WGPDMO appropriately. As in other cases, if an index for fish disease and/or parasite prevalence is to be constructed, then it must be specific for this particular problem. The construction, however, faces the same problem as in the situations discussed in the working document, namely that no *a priori* choice for a weighting or a construction principle exists. Therefore, to derive an index that quantifies the proportion of diseased fish, a stepwise procedure seems appropriate, starting with a simple index defined as the mean of the relevant disease prevalences, checking the amount of information that is lost in this way and then to revise the initial definition, as necessary.

In the discussion of this simple approach, several issues were raised:

- The prevalences that enter the index should be standardised for confounding factors such as age/size and possibly others.
- The decision on which factors should be considered for standardisation should be checked beforehand by appropriate statistical tests.
- The index might be improved by including intensity data in addition to prevalence. However, the ICES database presently does not provide intensity data, but could be made to do so in future. Those data are presently available only in national databases.
- The resulting index should better be termed a ‘disease index’, as effectively the disease (not the health) status is summarised.

Conclusions

- None of the 'health indices' reviewed describe the disease-related parameters of interest for the WGPDMO appropriately, warranting the development of a disease-specific index.
- A pilot study on the construction of a disease index for the prevalence of the main fish diseases could be initiated using German data which incorporates disease intensity and parasite prevalence information from studies in common dab (*Limanda limanda*) in the North Sea. Such a study can be used to identify potential problems that may be important for future larger scale studies.

Recommendations

The WGPDMO recommends that:

- a pilot study be carried out intersessionally by WGPDMO members to determine the feasibility of constructing a 'disease index', using dab (*Limanda limanda*) disease data obtained from the North Sea and that the WGPDMO should review the results of the study during its 2006 meeting (ToR for 2006).

Annex 8: Information on the distribution, causes and significance of the Summer Mortality syndrome in the Pacific oyster (*Crassostrea gigas*) and in other bivalve species – extracts from the WGPDMO 2005 Report

by T. Renault, S. Ford, J. F. Samain

The first description of Summer Mortality Syndrome in the Pacific oyster was in Japan in the 1940s. The syndrome was, and continues to be, associated with high mortality rates in Pacific oysters and other bivalves around the world. The causes remain unknown, but a multifactorial aetiology is suspected. Recently, a multidisciplinary approach including studies on pathology, genetics, physiology and immunology has been conducted in France (MOREST). The WGPDMO considered it important to have an overview of summer mortalities in Pacific oysters and in other molluscan species, with special emphasis on the results of the MOREST project.

The first description of the phenomenon known as "summer mortality" concerned oysters of the species *Crassostrea gigas* being cultured in numerous embayments along the Japanese Pacific coast. According to Koganezawa (1974), the mortalities began occurring in 1945 with the large-scale use of hanging culture methods (raft, longline, and rack). These "mass mortalities" (50 to 60%, or more) all had certain common features:

- The animals affected were one year old or older, and were the largest and fastest growing.
- The mortalities occurred in eutrophic waters, mostly during the spawning season, but shortly thereafter in some regions.
- Deaths began with the rise of temperatures to 21–22 °C or above and took place gradually over a spawning season.
- There was no (apparent) association with hydrographical conditions other than temperature.
- Bacteria were present in the affected oysters, but no other infective organism was associated with the mortalities.

The association with spawning and the highest temperatures of the season led Japanese investigators to examine the relationship between gonadal maturation, energy metabolism, and the mortalities (Mori, 1979). They reported that oxygen consumption, ciliary activity, and glycogen reserves all decreased during maturation and reached low points just before mortality began. The conclusion of these studies was that Summer Mortality in Japan was due to a "physiological disorder and metabolic disturbance derived by heavy gonad formation and massive spawning under high water temperature and eutrophication" (Koganezawa, 1974). In particular, it was thought that "overmaturation" of germ cells, i.e., a long residence time of ripe gametes within the gonad, induced pathological changes in the biochemical composition of oocytes that in turn led to death. The bacteria found in moribund oysters were considered secondary invaders of already weakened oysters.

Crassostrea gigas seed had been imported regularly for growout on the west coast of the United States and Canada since the early 1900s (Chew, 1990). In the late 1950s, mortalities of *C. gigas* were first noted on this coast (Glude 1975 in Cheney *et al*. (2000). They had many of the same features as those in Japan:

- The animals affected were 2 years old or older and had a high condition index.

- The mortalities occurred in high nutrient and high productivity areas, at water temperatures approaching 20 °C, varied greatly from area to area, and did not occur in all years.
- Results of early bacteriological assays were inconsistent, with some showing presence of bacteria and other failing to do so, but no other infective agent was associated with the mortality.

A Summer Mortality episode in Alaska in 1987 also involved unusually high temperatures (~20^{o}C) occurring during a period when the oysters contained mature or nearly mature gametes (Meyers *et al*., 1990). Experimental studies in the US further implicated gonadal maturation and loss of carbohydrate reserves in the mortality (Perdue *et al*., 1981) and showed that experimentally elevating temperature (to 21 °C) or adding high doses of microalgae to the tank seawater significantly increased mortality (Lipovsky and Chew, 1972).

Studies during the 1980s described histopathological evidence of bacterial involvement in Summer Mortality in the USA. The agent, a Gram-positive bacterium was later named *Nocardia crassostrea* (Friedman *et al*., 1991; Friedman *et al*., 1998). Pacific oyster nocardiosis, the disease caused by *N. crassostrea*, and Summer Mortality overlap both spatially and temporally (Elston, 1987), although not all instances of Summer Mortality involve the bacterium. Friedman et al. (1991) considered that *N. crassostrea* might be opportunistic, rather than the primary cause of Summer Mortality, although Elston *et al*. (1987) pointed out that the bacterium could be lethal.

A selective breeding program at the University of Washington produced families that showed greatly improved survival in both the field and in elevated-temperature laboratory trials (Beattie *et al*., 1980). Although mortality consistently occurred shortly after spawning, Perdue (1981) found no correlation between high and low mortality groups and carbohydrate levels. Unfortunately, the selected stocks were thinner, smaller and had slower growth than unselected stocks (Cheney *et al*., 2000). Meanwhile, techniques to induce triploidy in oysters were developed (Allen and Downing, 1986). Triploid oysters were commercially valuable because their reproductive output was minimal and they could be marketed during the entire year (the mass of gametes produced by diploid *C. gigas*, negatively affected taste and texture and made them unmarketable during the reproductive season.) Triploid oysters had another advantage: their reduced gamete production was likely to make them less susceptible to Summer Mortality.

A preliminary report of a comprehensive, recent investigation of the factors involved in Summer Mortality on the US west coast concluded that it is most likely caused by a suite of stressors: those already implicated, but also including possible links with low dissolved oxygen and phytoplankton blooms (Cheney *et al*., 2000). Interestingly, in this study, mortality of triploid oysters began earlier, rose more rapidly, and reached levels 8 to 28 percentage points greater than did mortality of diploids. The final report of this multi-year study has not yet been published, but members of the same investigative team have recently found oyster herpes virus in *C. gigas* from Tomales Bay, California, USA, where Summer Mortality has been reported for the past decade, although a causal relationship has not been established (Friedman *et al*., 2005).

A "summer mortality" of sorts has also been described in cultured eastern oysters, *C. virginica*, on the northeastern United States. It, too, affects fast growing oysters and begins when water temperatures approach or exceed 20–22^{o}C, and can kill up to 90 % of affected stocks within a few weeks (Bricelj *et al.*, 1992; Ford and Borrero, 2001). There is a genetic component, which has permitted the development of resistant strains (Lewis *et al.*, 1996), and it has even been associated with plankton blooms (Lee *et al.*, 1996). However, it affects only juvenile (<1 year old) oysters, as its name Juvenile Oyster Disease (JOD) implies. It further differs from *C. gigas* Summer Mortality in that JOD produces a distinct symptom: an organic deposit on the inner shell more reminiscent of Brown Ring Disease in the Manila clam, *Ruditapes philippinarum* in western Europe (Paillard and Maes, 1994). A newly described proteobacterium, *Roseovarius crassostrea*, predominates on the inner shell surface, including the organic deposit, of symptomatic oysters and increases in prevalence before symptoms or mortality begin; however, attempts to reproduce the characteristic organic deposit have been inconsistent Boettcher (2000).

Summer Mortality episodes, with losses of 80 to 90 %, have been reported for other bivalves, including the blue mussel, *Mytilus edulis*, in eastern Canada and in Maine, USA, and the Zhikong scallop, *Chlamys farreri*, in China (Xiao *et al*., submitted); Newell and Lutz, 1991; Myrand and Gaudreault, 1995). Mortalities of these species have important elements in common with *C. gigas* Summer Mortality:

- they occur in off-bottom culture and in late summer when temperatures are maximal;
- they typically affect reproductively mature or post-spawning animals;
- they can kill up to 80-90 % of affected groups;
- there is no histological evidence of a specific pathogen;
- in the case of mussels, at least, there is a genetic component to resistance and susceptibility (Myrand and Gaudreault, 1995).

Tremblay and colleagues (Tremblay *et al*., 1998a, 1998b, 1998c) have described a suite of physiological and biochemical differences between resistant and susceptible *M. edulis* stocks: compared to resistant stocks, susceptible mussels have lower heterozygosity, higher maintenance metabolism, lower scope for growth, lower O/N ratio, higher lysosomal membrane instability, and appeared less able to acclimate to the high temperatures of late summer when mortalities occur. Xiao *et al*. (submitted) reported somewhat reduced heterozygosity (9%) in cultured scallops, which experience mortality, compared to wild stocks. They also found an accumulation of organisms, including the large ciliate *Trichodina* sp., within the gill cavities of scallops experiencing summer mortalities. They postulated that heavy fouling and high stocking densities resulted in poor circulation, and perhaps oxygen depletion, in the growout cages and within the scallops' gill cavities, which would severely stress the scallops at high temperatures and during the period of reproduction. It might also foster the accumulation of potentially damaging gill symbionts. Some evidence also exists of viral involvement in the scallop deaths (Wang *et al*., 2002).

The collective evidence available at the start of the French MOREST program suggested that Summer Mortality affecting adult bivalves is not caused by a single etiological agent, but involves complex interactions between environment, oyster and pathogens. The most important external factor seemed to be elevated temperature coming at a time when the intrinsic factors gametogenesis and spawning place the animal in a relatively unstable physiological condition. Any other external factor that exacerbates this instability, including further stress and the presence of opportunistic invaders, may push the animals over a threshold from which they cannot recover.

Main results of the "MOREST" project on Summer Mortality in the Pacific oyster (Crassostrea gigas)

By J. F. Samain, P. Boudry, L. Degremont, P. Soletchnik, M. Ropert, E. Bédier, J. L. Martin, J. Moal, M. Mathieu, S. Pouvreau, C. Lambert, J. M.Escoubas, J. L. Nicolas, F. Le Roux, T. Renault, T. Burgeot, C. Bacher (MOREST network of French laboratories)

Pacific oyster production on the French coasts has experienced periodic mass mortalities for at least 20 years (Renault *et al*., 1994; Goulletquer *et al*,. 1998; Soletchnik *et al*., 1999). The syndrome, too, is known as Summer Mortality. Factors such as food limitation, oxygen depletion, salinity and temperature variations do not appear as single direct causative agents of the syndrome (Soletchnik *et al*., 1998). Some authors suggest that many of the mortalities occurring in *C. gigas* are the result of multiple factors or stressors, including elevated temperatures, physiological stress associated with maturation, aquaculture practices, pathogens, or pollutants (Goulletquer *et al*., 1998). It could be assumed that a background rate of mortality due to environmental conditions, physiology and genetic makeup, might be affected by infectious agents. As with many filter-feeding benthic invertebrates, oysters are permanently exposed to various microorganisms. Efficient humoral and cellular defence mechanisms normally help to limit the proliferation of microorganims in animals (Harris-Young *et al*., 1995; Cheng, 1996). Since 1996, the Laboratory of Shellfish Farming of Poitou-Charentes has studied the phenomenon of mortality in a culture area in the south of Marennes-Oleron Bay (Ronce-Perquis, Charente-Maritime, France) (Lodato, 1997). Despite inter-annual and inter-stock variability, mortality of oysters reared on sediment (or a few centimetres above) is significantly higher, by 20-30 %, than mortality of animals on racks 50 cm or 70 cm above the sediment (Soletchnik *et al*., 1999). Previous studies also showed that energy allocation to reproduction, as well as shell and soma growth, were less important near the sediment than on racks (Goulletquer *et al*., 1998; Soletchnik *et al*., 1999; 2003).The MOREST project on *C. gigas* oyster Summer Mortality was focused on the complex interactions hypothesized by many authors between environment, oysters and pathogens. Such multifactorial associations led us to organize a research network (including genetics, physiology, immunology, pathology, ecotoxicology, and ecology) all using the same biological material. This strategy, and the coupling of field sampling and experimental studies, allowed us to progressively classify the importance of the different factors involved in Summer Mortality. Natural and hatchery-produced spat were compared at three oyster-production areas in France. Regardless of whether they were naturally set or of hatchery origin, oysters died during the reproduction period after temperatures reached 19 °C. Thus, in southern areas, temperatures accelerated gametogenesis in small spat (10 mm) as well as in adults, and mortality appeared in both development stages. Sexual maturation proceeded more slowly in northern France and consequently spat mortality was low compared to 18-month old oysters.

- A temperature over 19 °C appeared the primary necessary condition for Summer Mortality in France, but was not, by itself, sufficient to produce mortalities. This temperature is associated with the final stage of gametogenesis, when energy storage is minimal and when scope for growth becomes very low. It is also an optimal temperature for bacterial (*Vibrio* spp.) proliferation as well as for anaerobic production of H_2S and NH_4^+ from accumulated organic matter in the sediment, which is considered one of the major stressing factors in the environment.
- Nutrient level is a second critical parameter as high levels favour reproductive effort and may lead to energy imbalance. Haemocyte numbers decreased during the gametogenesis period, regardless of the food supply. Phagocytosis capacity decreased inversely to food level and reproductive effort. Experimental challenges or natural infection under these conditions led to mortality rates related to this decrease. Other immune parameters or tools are under study to better document these relationships (Lambert *et al.*, 2003; Gueguen *et al.*, 2003; Montagnani *et al.*, 2004, 2005).
- Gonadal maturation is known as an intrinsic factor of risk in Summer Mortality (Glude, 1975; Mori, 1979; Perdue *et al*., 1981). Thus, triploid oysters (with reduced maturation) were also tested. Results showed that triploids, which suffered the lowest mortalities, presented higher potential defence capacities than did diploids. Because Summer Mortality may result from a combination of environmental factors, physiological status, and presence of pathogens (Lacoste *et al*., 2001; Leroux *et al*., 2002), higher defence capacities may be an important factor to resist this phenomenon. In some rare observations, triploids demonstrating an unusually high reproductive state were as susceptible to summer mortality as diploids.

- Some stressor was necessary to induce mortality even when temperature and reproductive condition were favourable for Summer Mortality outbreaks. A simple transfer of oyster could induce mortality in these conditions. Proximity to sediment appeared to be a consistent detrimental factor (Soletchnik *et al*., 2005), probably because of its high organic content. High fresh water run-off from surrounding rivers was also correlated with elevated mortality.
- A genetic component evidenced by divergent selection in two generations was confirmed during the project (Dégremont *et al.*, 2005). In the same area or in controlled experimental conditions, "Susceptible" (S) strains invested more energy in reproduction than did "Resistant" (R) oysters under similarly high food conditions. Molecular studies comparing these two phenotypes are under study (Huvet *et al.*, 2004) and are now focused on pathways of glucose metabolism and on immune mechanisms (Bacca *et al*., 2005).
- Different pathogens were isolated from moribund oyster. Herpesvirus (OsHV-1) was mostly detected in juvenile mortality events and when temperature was high. Different strains and species of Vibrios (including *V. splendidus* and *V. estuarianus*) were isolated from moribund one- and two-year old oysters and identified by molecular techniques (Le Roux *et al.*, 2002; 2004). Their virulence, as tested by injection in the adductor muscle, varied according to strain and species (Labreuche *et al.*, 2005). The effect of environmental factors on transmission and expression of virulence is also under study. One of the *Vibrio splendidus* strains has been sequenced, and numerous genes coding for virulence factors were found. This model will offer possibilities to better understand the expression of virulence under differing environmental and host conditions. It emphasizes that necessity for interactions between oyster physiology and environmental parameters to occur in order to produce Summer Mortality.

None of these different factors can separately induce summer mortality, and all of these conditions seem necessary to reproduce the event. According to these interactions, strategies to forecast and prevent the risk will be devised.

References

Allen, J., S.K., and Downing, S.L., 1986. Performance of triploid Pacific oysters, *Crassostrea gigas* (Thunberg). I. Survival, growth, glycogen content, and sexual maturation in yearlings. J. Mar. Biol. Ecol., 102, 197–208.

Bacca, H, Huvet, A, Fabioux, C., Daniel, JY, Delaporte M, Pouvreau S, Van Wormhoudt A, Moal, J. 2005. Molecular cloning and expression of the oyster glycogen phosphorylase and glycogen synthase genes. Comparative Biochemistry and Physiology Part B, 140, 635–646.

Beattie, J.H., Chew, K.K. and Hershberger, W.K., 1980. Differential survival of selected strains of Pacific oysters (*Crassostrea gigas*) during summer mortality. Proc. Nat. Shellfish. Ass., 70, 184–189.

Bricelj, V.M., Ford, S.E., Borrero, F.J., Perkins, F.O., Rivara, G., Hillman, R.E., Elston, R.A., and Chang, J., 1992. Unexplained mortalities of hatchery-reared, juvenile oysters, *Crassostrea virginica* (Gmelin). J. Shellfish Res., 11, 331–347.

Cheney, D.P., MacDonald, B.F., and Elston, R.A. 2000. Summer mortality of Pacific oysters, *Crassostrea gigas* (Thunberg): initial findings on multiple environmental stressors in Puget Sound, Washington, 1998. J. Shellfish Res., 19, 353–359.

Cheng, T.C., 1996. Hemocytes : forms and functions, p. 299-333. Ed. by V.S. Kennedy, R.I.E. Newell, and F. Eble. *In* The eastern oyster Crassostrea virginica. Maryland Sea Grant College, College Park.

Chew, K.K. 1990. Global bivalve shellfish introductions. World Aquaculture, 21, 9–22.

Dégremont, L, Bédier, E., Soletchnik, P., Ropert, M., Joly, J.P., Huvet, A., Moal, J., Samain, J.F., and Boudry, P. 2005. Variability of survival, growth and yield of hatchery-produced

Pacific oyster spat (*Crassostrea gigas*). I. Relative importance of family, site, timing of placement in the field and their interactions. Aquaculture in press

Elston, R.A., Beattie, J.H., Friedman, C., Hedrick, R. and Kent, M.L. 1987. Pathology and significance of fatal inflammatory bacteraemia in the Pacific oyster, *Crassostrea gigas* Thunberg. J. Fish Dis., 10, 121–132.

Ford, S.E., and Borrero, F.J. 2001. Epizootiology and pathology of Juvenile Oyster Disease in the Eastern Oyster, *Crassostrea virginica*. J. Invertebr. Pathol., 78, 141–154.

Friedman, C.S., Beaman, B.L., Chun, J., Goodfellow, M., Gee, A. and Hedrick, R.P. 1998. *Nocardia crassostreae* sp. nov., the causal agent of nocardiosis in Pacific oysters. International Journal of Systematic Bacteriology, 48, 237–246.

Friedman, C.S., Beattie, J.H., Elston, R.A., and Hedrick, R.P. 1991. Investigation of the relationship between the presence of a Gram-positive bacterial infection and summer mortality of the Pacific oyster, *Crassostrea gigas* Thunberg. Aquaculture, 94, 1–15.

Friedman, C.S., Estes, R.M., Stokes, N.A., Burge, C.A., Hargove, J.S., Barber, B.J., Elston, R.A., Burreson, E.M., and Reece, K.S. 2005. Herpes virus in juvenile Pacific oysters *Crassostrea gigas* from Tomales Bay, California, coincides with summer mortality episodes. Dis. Aquat. Org., 63, 33–41.

Glude, J.B. 1975. A summary report of the Pacific Coast oyster mortality investigations 1965-1972. Proceedings of the Third U.S.-Japan Meeting on Aquaculture at Tokyo, Japan, October 15–16, 1974. p.28.

Goulletquer, P., Soletchnik, P., Le Moine, O., Razet, D., Geairon, P., Faury, N., and Taillade, S. 1998. Summer morality of the Pacific cupped oyster *Crassostrea gigas* in the Bay of Marennes-Oleron (France). ICES Mariculture Committee CM 1998/CC. pp. 14–21.

Gueguen, Y., Cadoret, J.P., Flament, D., Barreau-Roumiguiere, C., Girardot, A.L., Garnier, J., Hoareau, A., Bachère, E., and Escoubas, J.M. 2003. Immune gene discovery by expressed sequence tags generated from hemocytes of the bacteria-challenged oyster, *Crassostrea gigas*. Gene 16: 139–145.

Harris-Young, L., Tamplin, M.L., Mason, J.W., Aldrich, H.C., and Jackson, J.K. 1995. Viability of *Vibrio vulnificus* in association with hemocytes of the American oyster (*Crassostrea virginica*). Appl. Environ. Microbiol. 61: 52–57.

Huvet, A., Herpin, A., Dégremont, L., Labreuche, Y., Samain, J.F., Cunningham, C. 2004. The identification of genes from the oyster *Crassostrea gigas* that are differentially expressed in progenies exhibiting opposed susceptibility to summer mortality. Gene, 343, 211–220.

Koganezawa, A., Year. Present status of studies on the mass mortality of cultured oysters in Japan and its prevention. In: (Ed.), Third U.S.-Japan Meeting on Aquaculture, Tokyo, Japan. Journal, 29–34.

Lacoste, A., Jalabert, F., Malham, S., Cueff, A., Gelebart, F., Cordevant, C., Lange, M., and Poulet, S.A. 2001. A Vibrio splendidus strain is associated with summer mortality of juvenile oysters *Crassostrea gigas* in the Bay of Morlaix (North Brittany, France). Diseases of Aquatic Organisms, 46: 139–145.

Labreuche, Y., Soudant, P., Gonçalves, M., Lambert, C., and Nicolas, J.-L. 2005. In vitro effects of Extracellular Products (ECPs) from the pathogenic *Vibrio aestuarianus* strain 01/32 on the oyster *Crassostrea gigas* cellular immune responses. Developmental & Comparative Immunology (In press).

Lambert C., Soudant, P., Choquet, G., and Paillard, C. 2003. Measurement of *Crassostrea gigas* hemocytes oxidative metabolism by flow cytometry and the inhibiting capacity of pathogenic vibrios. Fish Shellfish Immunol. 15(3), 224–240.

Lee, M., Taylor, G.T., Bricelj, V.M., Ford, S.E., and Zahn, S. 1996. Evaluation of *Vibrio* spp. and microplankton blooms as causative agents of Juvenile Oyster Disease in Crassostrea virginica (Gmelin). J. Shellfish Res., 15, 319–329.

Le Roux, F., Gay, M., Lanbert, C., Waechter, M., Poubalanne, S., Chollet, B., Nicolas, J.L., and Berthe, F. 2002. Comparative analysis of *Vibrio splendidus*-related strains isolated during Crassostrea gigas mortality events. Aquatic Living Resources, 15: 251–258.

Le Roux, F., Gay, M., Lambert, C., Nicolas, J.-L., Gouy, M., and Berthe F. 2004. Phylogenetic study and identification of *Vibrio splendidus* related strains based on GyrB gene sequences. Diseases of Aquatic Organisms, 58: 143–150.

Lewis, E.J., Farley, C.A., Small, E.B., and Baya, A.M. 1996. A synopsis of juvenile oyster disease (JOD) experimental studies in *Crassostrea virginica*. Aquat. Liv. Res., 9, 169–178.

Lipovsky, V.P. and Chew, K.K., 1972. Mortality of Pacific oysters *Crassostrea gigas*: the influence of temperature and enriched seawater on survival. Proc. Nat. Shellfish. Ass., 62: 72–82.

Lodato, M.I. 1997 Mortalité estivale de l'huitre creuse, *Crassostrea gigas*, sur les bancs ostréicoles de Perquis et Ronce (bassin de Marennes-Oléron) : étude des pratiques culturales et des caractéristiques biologiques et spatiales des élevages. Thèse de Dr Vétérinaire, Ecole Nationale vétérinaire de Nantes, 127 pp.

Meyers, T.R., Short, S., and Eaton, W. 1990. Summer mortalities and incidental parasitism in cultured Pacific oysters in Alaska. J. Aquat. An. Health, 2, 172–176.

Montagnani, C., Kappler, C., Reichhart, J.M., and Escoubas J.M. 2004. Cg-Rel, the first Rel/NF-_B homolog characterized in a mollusk, the Pacific oyster *Crassostrea gigas*. FEBS Letter, 561: 75–82.

Montagnani, C, Tirape, A., Boulo, V., and Escoubas, JM. 2005. Origin of the two Cg-timp mRNA produced by oyster hemocytes and expression during embryogenesis. Dev. Comp. Immunol. In press.

Mori, K. 1979. Effects of artificial eutrophication on the metabolism of the Japanese oyster *Crassostrea gigas*. Mar. Biol., 53: 361–369.

Myrand, B., and Gaudreault, J. 1995. Summer mortality of blue mussels (*Mytilus edulis* Linneaus, 1758) in the Magdalen Islands (Southern Gulf of St Lawrence, Canada). J. Shellfish Res., 14: 395–404.

Newell, C., and Lutz, R. 1991. Growth and survival of cultured mussels in Maine. Bulletin of the Aquaculture Association of Canada, 91, 47–53.

Paillard, C., and Maes, P. 1994. The brown ring disease symptom in the manila clam, *Ruditapes philippinarum*: establishment of a classification system. Dis. Aquat. Org., 19, 137–146.

Perdue, J.A., Beattie, J.H., and Chew, K.K. 1981. Some relationships between gametogenic cycle and summer mortality phenomenon in the Pacific oyster (*Crassostrea gigas*) in Washington state. J. Shellfish Res., 1: 9–16.

Renault, T., Le Deuff, R.M., Cochennec, N., and Maffart, P. 1994. Herpesvirus associated with mortalities among Pacific oyster, *Crassostrea gigas*, in France - Comparative study. Revue Médecine Vétérinaire, 145(10): 735–742.

Soletchnik, P., Le Moine, O., Faury, N., Razet, D., Geairon, P., Goulletquer, P., and Forest, G. 1998. Spring and summer mortalities of the Pacific cupped oyster *Crassostrea gigas* in the Marennes Oleron Bay: Pilot study from Ronce and Perquis leasing grounds. RIDRV-RA/RST/98.02/Ifremer La Tremblade, 55p.

Soletchnik, P., Le Moine, O., Faury, N., Razet, D., Geairon, P., and Goulletquer, P. 1999. Mortalité de l'huître creuse *Crassostrea gigas* dans le bassin de Marennes-Oléron : étude de la variabilité spatiale de son environnement et de sa biologie par un système d'informations géographiques (SIG). Aquatic Living Resources, 12(2): 131–143.

Soletchnik, P., Ropert, M., Huvet, A., Moal, J., Degrémont, L., Bédier, E., Bouget, J. F., Dubois, B., Martin, J. L., Enrique-Diaz, M., Faury, N., Lemoine, O., Renault, T., Gagnaire, B., and Samain, J. F. 2003. Characterization of summer mortality of *C. gigas* in France, in relation to environmental parameters. J. Shellfish Res. 22: 354.

Soletchnik P., Lambert, C., and Costil, K. 2005. Summer mortality of *Crassostrea gigas* (Thunberg) in relation to rearing environmental conditions. Journal of Shellfish Research (in press).

Tremblay, R., Myrand, B. and Guderley, H., 1998a. Temporal variation of lysosomal capacities in relation to susceptibility of mussels, *Mytilus edulis*, to summer mortality. Mar. Biol., 132, 641-649.

Tremblay, R., Myrand, B., and Guderley, H. 1998b. Thermal sensitivity of organismal and mitochondrial oxygen consumption in relation to susceptibility of blue mussels, *Mytilus edulis* (L.), to summer mortality. J. Shellfish Res., 17: 141–152.

Tremblay, R., Myrand, B., Sevigny, J.M., Blier, P., and Guderley, H. 1998c. Bioenergetic and genetic parameters in relation to susceptibility of blue mussels, *Mytilus edulis* (L.) to summer mortality. J. Exp. Mar. Biol. Ecol., 221: 27–58.

Wang, C., Wang, X., Song, X., Wang, Y., Huang, J. and Song, W. Year. Possible virus-like etiology causing massive death of scallop Chlamys farreri in north China. In: (Ed.), World Aquaculture 2002, Beijing, China. Journal, 777.

Xiao, J., Ford, S.E., Yang, H., Zhang, G., Zhang, F., and Guo, X., Studies on mass summer mortality of cultured Zhikong scallops (Chlamys farreri Jones et Preston) in China. Aquaculture, submitted.

Annex 9: Proposed Draft Resolution 2005

The **Working Group on Marine Shellfish Culture** [WGMASC] (Chair: Peter Cranford, Canada*) will meet in Galway, Ireland from 18–20 April 2006 to:

o) Prepare a state of knowledge report comparing and contrasting the standard methods used to measure stress indicators in shellfish and provide a discussion of how they would be used to diagnose incidents of cultured shellfish mortality;

p) Complete the report regarding the discussion on the standard methodologies used to estimate shellfish performance indices. To finalise the WGMASC work on the ToR comprising a review of the effects of HAB and Disease in relation to the performance and carrying capacity of shellfish culture. To prepare a review of management systems in shellfish aquaculture, identifying similarities and differences and assessing their utility to the regulators and industry. This will be prepared intersessionally and approved in 2006 with a view to closing this part of the term of reference.

q) Compare the use of hatchery-reared spat versus natural spat settlement for scallop production through fisheries, in the view of improving the management of this resource. Culture techniques, population dynamics parameters , such as growth to the commercial size and mortality, monitoring during the ongrowing stages, yields, number and cost of seeded spat vs. fished adults, potential impacts of culture and dredging should be collected from different fisheries during intersessional work, to prepare a report assessing the interest of using hatchery reared spats on the scallops fisheries.

Supporting Information

Priority:	WGMASC is of fundamental importance to ICES environmental science and advisory process and addresses specific issues of the ICES Strategic Plan.
Scientific Justification and relation to Action Plan:	Action Plan references: a) 2.6, 3.4, 3.11, 4.7 b) 1.10, 3.10, 3.14, 4.6, 6.3 c) 2.12, 3.11, 4.7 a) Spat availability is of a primary importance for the shellfish industry. It relies upon both the hatchery production, as reviewed recently by WGMASC, and the collection of spatfall from the field. Nowadays, many of the recent development of shellfish production would be based on hatchery produced spat, depending on the country. This is observed for scallop production, which are either reared in open waters by means of longline culture or bottom culture, dived or dredged in coastal areas. Stocks depletion in scallops beds, in certain countries, have led to the use of hatchery reared spat for reseeding, in order to sustain the production. Also mussels produced by cultivation can be used in restocking programmes, while fished mussels can be farmed as spats or adults. Oyster production still heavily relies on the availability of natural spat settlement, even for restoration programmes. Therefore, a continuum exists for the shellfish production, from fisheries to aquaculture. This aspect and the scallop industry is not addressed by any of the ICES WG (MCC or LRC), while management issues and concerns, related with such a variety of production means, are growing in ICES countries. Several aspects needs to be specifically addressed, in reference to the ICES action plan, and according to the interactions among different science committees (MCC and LRC – implication of ranching on harvesting wild populations. b) Shellfish production is based on the use of the natural productivity of coastal waters as a source of food. Shellfish require a clean environment and is, in essence, integrating the environmental conditions of the growing area. Unexplained mortalities have an immediate negative effect on both producers and market share. These can be caused by predation, HAB, diseases, pollution, and water quality or any combination thereof. Stress in animals can be caused by either chronic or acute extrinsic factors that may act to decrease the fitness of the animal or to cause its premature death. Use will be made of the biological effects of contaminants literature that is available within ICES. Chronic factors will often be manifested by changes in the overall health of the animal (i.e., in a stepwise cellular-tissue-organ-physiological levels). Acute factors produce immediate responses that may only show up at the molecular\cellular levels. Therefore, detecting acute effects is usually done with biochemical techniques. Different bio-indices will be reviewed and their usefulness determined: adenylate energy charge (AEC), heat shock proteins, total oxy-radical scavenging capacity (TOSC), glycogen content, metallothioneins (MT), cytochrome P4501A1 activity, DNA damage, total lipids and histology. Work will also be cross-referenced with WGEIM. c) Shellfish production accounts for half of the mariculture production in ICES. As such, issues related to shellfish production, in relation to the environment and technological development of the industry need to be addressed within ICES. The effects of the environmental perturbations on shellfish production are dramatic and sudden. There is a need to identify the causes of potential

	impacts and their effects on the production of shellfish, in order to establish the requirements for the industry in terms of water quality, ecological perturbations and biological competitors.. The information will also be useful for determining the ecological requirements for shellfish production in coastal areas. The Working Group has given priorities to the different impacts : 1- Carrying capacity (Hydrographic factors, Primary productivity, food supply), 2- Predation, 3- fouling, 4- HAB Blooms,5- Disease, 6- Pollution (water quality). The Chair of WGMASC will cross-reference all work with the Chairs of WGEIM and WGHABD
Resource Requirements:	none.
Participants:	The Group is normally attended by some 7-10 members and guests
Secretariat Facilities:	None
Financial:	No financial implications
Linkages To Advisory Committees:	The linkage with ACME goes through other WG (see below)
Linkages to other Committees or Groups:	There is a very close relationship with groups of Mariculture Committee WGPDMO and WGEIM. It also is of close relevance to the WGITMO. Links may be fruitfully explored with Working Group on Ecosystem Effects of Fisheries, in order to propmote an ecosystem approach of the effect of Mariculture. The living resources Committee shall be informed of content of ToR c, on the use of different sources of spat for scallop,s mussels and oysters, both to enhance fishery grounds or for shellfish culture
Linkages to other Organisations:	The WAS and EAS, as well as shellfish associations in different countries are consodered as partners organisations,notably through crossed memberships
Secretariat Marginal Cost Share:	N/A

Annex 10: Action Plan Progress Review 2005

YEAR	COMMITTEE ACRONYM	COMMITTEE NAME	EXPERT GROUP	REFERENCE TO OTHER COMMITTEES	EXPERT GROUP REPORT (ICES CODE)	RESOLUTION NO.		
2004/2005	**MARC**	**Mariculture**	**WGMASC**		2004\F:05	2F05		
Action **Plan N°**	**Action Required**	**ToR's**	**ToR**	**Satisfactory Progress**	**No Progress**	**Unsatis-fatory Progress**	**Output (link to relevant report)**	**Comments (e.g., delays, problems, other types of progress, needs, etc.**
1.3,2.4, 2.5,2.6, 3.9,6.3	Please see items below	Update the synthesis and prepare a publication on the development of shellfish hatcheries within ICES countries. This will examine the technical infrastructure and methods (water treatment, broodstock conditioning, feeding schedules, etc.) of the different hatcheries, the proportion of cultured animals to wild conspecifics being used as broodstock and the application of genetic tools (e.g., triploids) to develop hatchery strains	a)	S				The group has obtained valuable data on molluscs hatcheries among ICES countries. However, it may be considered that gathering such informations about annual shellfish production is beyond the scope of this WG. It is recommended that ICES countries are encouraged to collect these data, and the ToR be only reacrtivated if new data or trends are observed in that field.
1.10,3.10, 3.14,4.6, 6.3	Please see items below	Prepare a state of knowledge report comparing and contrasting the standard methods used to measure stress indicators in shellfish and provide a discussion of how they would be used to diagnose incidents of cultured shellfish mortality	b)				WGPDMO 2005 Section 8	
2.12,3.11, 4.7	Please see items below	c) assess and provide a critique of the standard methodologies used to estimate shellfish performance indices as related to examining the carrying capacity of the growing area. This will include a review of the effects of HABS, disease and pollution in relation to the performance and carrying capacity of shellfish culture.	c)				WGEIM05 ToR d	

	ACTION PLAN NOS AND SUBJECT. TO BE CROSS LINKED TO TORS:
1.3	Increase knowledge of the effects of physical forcing, including climate variability, and biological interactions, on recruitment processes of important commercial species. [MHC/OCC/RMC/LRC/MARC/BCC/DFC]*
1.10	Develop better tools and training opportunities for monitoring and observation of physical, chemical and biological properties of marine ecosystems. [FTC]* [Other Science Committees]
2.4	Update the ICES Code of Practice on Introductions and Transfers and Transfers of Non-indigenous Organisms, including genetically modified organisms. [MARC/ACME/DFC]
2.5	Assess and evaluate the genetic consequences of human-induced selective factors, whether intentional (such as selective breeding for mariculture) or unintentional (such as selective effects of fishing). [MARC/LRC/ RMC/DFC/ACE/ACME]
2.6	Evaluate and assess the intra- and interspecific interactions of wild and farm-reared stock as well as disease and genetic interactions. [MARC/LRC/DFC]
2.12	Evaluate and increase knowledge of the effects of human activities on the productive capacity of estuarine and freshwater habitats of diadromous fish. [MHC/OCC/MARC/BCC/DFC]
3.9	Develop standard culture conditions under which strains, stocks, or species might be tested to evaluate their performance [MARC/DFC°
3.10	Review and inform clients regarding the use of major technological advances in mariculture that have significantly improved marine finfish production capabilities or survival [MARC/ACME/DFC]
3.11	Evaluate information on technological change in mariculture, including the utilisation of new species, with particular emphasis on the consequences for production and the environment. [MARC/ACME]
3.14	Provide information to the mariculture industry regarding effects of organic loading, diseases, and chemical treatments. [ACME/MARC/DFC]
4.6	Develop document guidelines for the preparation of Environmental Impact Assessments, and appropriate monitoring programmes. [MARC/MHC/ACME/ACE]
4.7	Review issues of sustainability in mariculture, including interactions between mariculture and other users of resources in the coastal zone, and between cultured and wild stocks. [MARC/DFC/ACME/ACE]
6.3	Encourage the production of high-quality scientific publications by ICES through a coordinated publications policy, involving continuous review of ICES scientific output and proactive support for its publications through diverse routes. [Publications Committee (PUB)/CONC/all Science Committees]