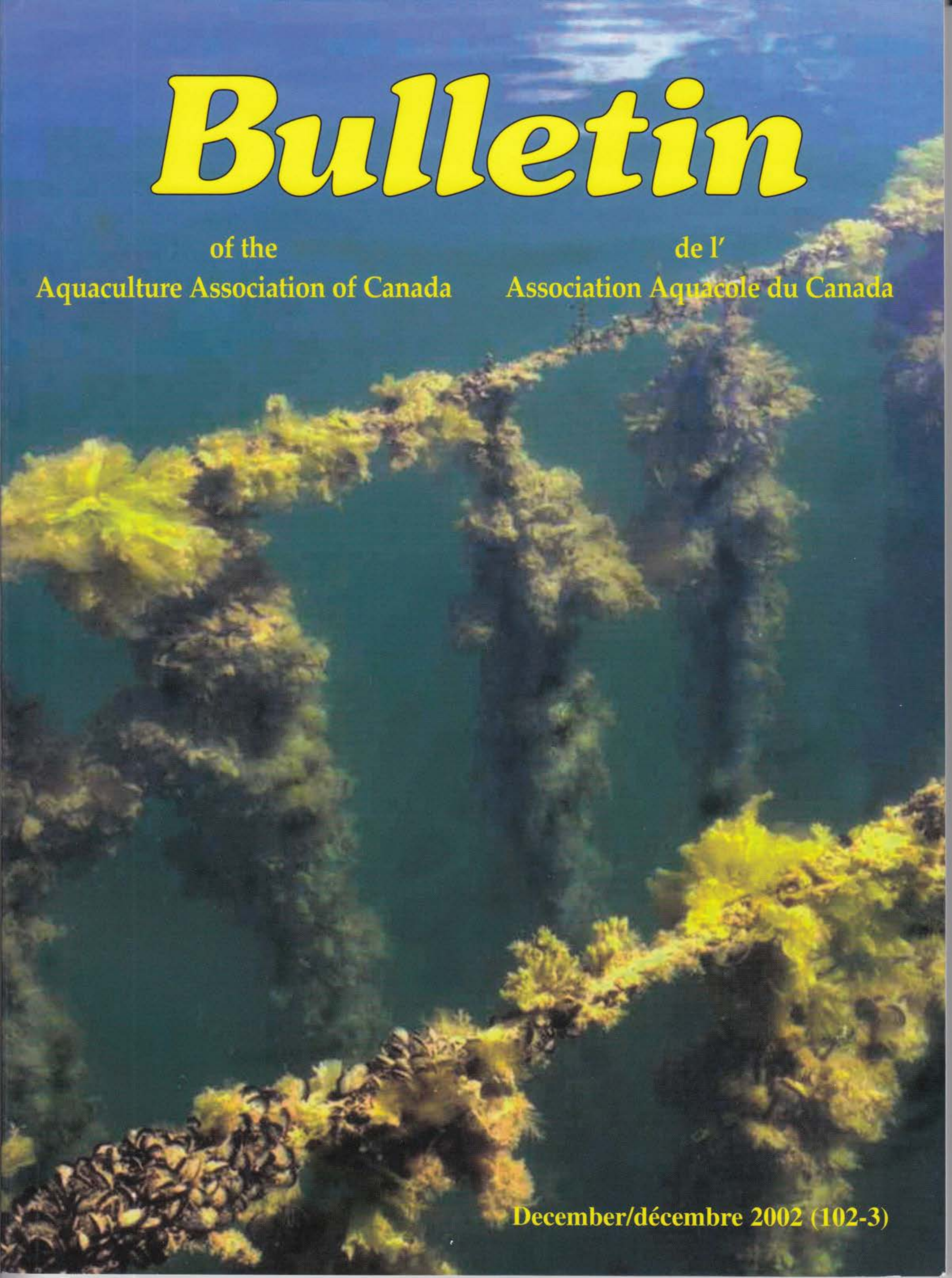

Bulletin

of the
Aquaculture Association of Canada

de l'
Association Aquacole du Canada

December/décembre 2002 (102-3)

Contents

Proceedings of the First International Mussel Forum

Aquaculture Canada^{OM} 2002, Charlottetown, PEI, 17-20 September 2002

Bulletin de l'Association aquacole du Canada

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Front cover: Suspended culture of Greenshell™ mussels in Marborough Sounds, New Zealand, an area of drowned river valleys that closely resembles the rias of Spain. Greenshell™ is the trademark of the New Zealand green-lipped *(Perna canaliculus)* mussel industry and all *P. canaliculus* grown in suspended culture in New Zealand qualify to use the trademark. The species is native to New Zealand and is not grown anywhere else in the world. [New Zealand Mussel Industry Council photo]

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Introduction

First International Mussel Forum

The idea of an international mussel forum originated during the early stages of the Aquaculture Association of Canada's (AAC) planning for Aquaculture Canada 2002 (AC02). The conference was being held in Prince Edward Island (PEI) in September 2002, and given that PEI is the mussel production capital of North America, it was a natural choice to hold an international mussel event in conjunction with the conference. To our knowledge there had been no major effort in the past 20 years to bring together a large international audience concerned with all aspects of commercial mussel culture. Thus, the idea for the First International Mussel Forum (FIMF) was borne.

The FIMF was organized by a steering committee consisting of: Cyr Couturier (Chair AC02, AAC), Crystal McDonald (Chair Trade Show, PEI Aquaculture Alliance), Jay Parsons (AC02 Program Chair, Marine Institute), Bob Johnston (FIMF Coordinator, PEI Dept. Fisheries, Aquaculture and Environment), and Richard Gallant (PEIDFAE). Additional personnel assisting with logistics included Bob Thomson (rapporteur, PEIDFAE), Neil McNair (audiovisual, PEIDFAE), and a suite of volunteers.

By all accounts, the FIMF was a great success with over 330 delegates from 13 countries (see list of participants on p. 111), including growers, suppliers and processors. In addition, the AC02 trade show included more than 30 booths devoted almost entirely to mussel aquaculture. Over two full days, the FIMF included a keynote presentation by Douglas McLeod, chairman of the Association of Scottish Shellfish Growers, and country overviews from the top 10 producing countries in the world. There were also 3 special sessions focusing on topical issues for the advancement of the global mussel industry. In addition to the invited presentations given during the FIMF, there were an additional 29 technical, scientific and business presentations given on mussel culture during the AC02 meeting, for a total of more than 40 mussel presentations in a little over 2 days of sessions! Simultaneous translation was provided during the FIMF to maximize participation and attendance.

An event such as the FIMF would not be possible without sponsors and volunteers. We are extremely grateful for the financial support of the Atlantic Canada Opportunities Agency (ACOA) for providing funding for hosting this international event and publishing these proceedings. Without this support, the event would not have been the success it has been. The Aquaculture Association of Canada, the Prince Edward Island Aquaculture Alliance and the Prince Edward Island Department of Fisheries, Aquaculture and Environment made signficant financial contributions to the event as well. We are extremely grateful for the professional demeanor (and patience) of the FIMF Editor, Susan Waddy. We also thank the following for providing support for events and activities associated with the FIMF: Canadian Heritage, PEI Government, Newfoundland Marine Farms, IntraFish, Office of the Commissioner for Aquaculture Development, Bank of Nova Scotia, Marine Institute, Contact Canada, Agriculture & Agrifoods Canada, and Cooke Aquaculture. Most of all we thank our attendees and all those who made the FIMF a huge success. We look forward to the Second International Mussel Forum, which is soon to be announced.

The following pages include the proceedings of the FIMF. We hope you will enjoy them.

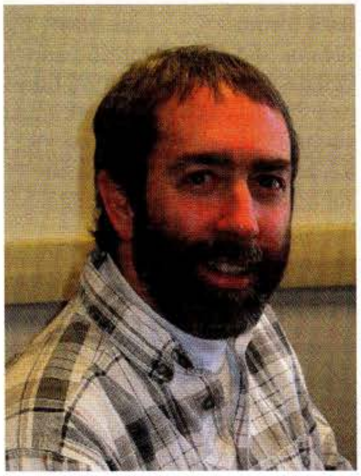
Cyr Couturier
Associate Editor and FIMF Co-Convenor

We gratefully acknowledge the financial support of the Atlantic Canada Opportunities Agency in hosting the First International Mussel Forum

Nous remercions l'appui financier de l'Agence de promotion économique du Canada Atlantique pour le Premier forum international des moules

President's Column

Do We Know Where We Are Going?



One of the benefits and challenges as president of the AAC is having a column in the *Bulletin* in which you can share your views of the world. As a result of this opportunity, I thought I might share some of my recent thoughts on the development of our marine resources in Canada.

I feel that society is now at a pivotal point in the evolution of human history where great changes and decisions will have to be made for the use of the marine environment. In some senses, we are still treating our coastal waters as a large, black box into which we dispose our daily wastes and out of which we harvest some of our food for the nourishment of our ever-growing population. To be fair, there is a growing segment of the public and resource management within various local institutions that recognize the impacts we are having on our coastal zones, and are striving to understand and protect these natural resources. Currently occupying the public's consciousness are questions such as: How do we maintain acceptable species diversity? What are the carrying capacities of various environments? and What spatial scales are required to maintain a healthy marine ecosystem? Part of the problem in managing these areas is that we do not understand enough of the basic processes that are driving the coastal zone populations to either manage or protect them. Therefore, the default position we are adopting is usually one of a "preservationist" policy where we try to maintain populations in some semblance to what they are today or have been in the recent memorable past using methods that have never really been adequately tested as to their effectiveness.

One of the main problems with the "preservationist" policy is that it is very difficult to decide where to set the benchmark for the state of preservation of existing populations. For example, based on fishery records and the memories of many old, now-retired fishermen, the abundance of some animal populations were far greater 50-100 years ago than they are today. However, in most cases, we do not know what the actual densities of the animals were nor what other associated species were present at the time and what their relative abundances were in comparison to the target species. Thus, it will be very difficult to get back to those population assemblages. Also, animal populations generally fluctuate naturally over time. Do you choose a single point in time on which to base the management measures or do you try to protect the system and allow it to fluctuate within certain boundaries? How can we handle a changing environment responding to issues such as global warming? These are questions that are very difficult to answer and create a strict set of guidelines to hand to a resource manager.

One of the ways forward may be to look to the terrestrial system for some examples and answers. I could argue that our exploitation and development of marine environmental systems are simply a reflection of the same pattern we have exerted on terrestrial systems as our population numbers increased. Because of the inherent difficulties in working in the marine environment, this pattern of exploitation has simply been delayed. If we use the terrestrial system as a model, we can see that there has been zoning of the land mass into industrial growth, food production and human habitation while other areas are set aside as natural refuges for other species with which we share the planet. In all the above categories, there are cases where this development has been done fairly well and others where it has been an unmitigated disaster. The challenge for the development of the marine environment is to learn from these mistakes, choose the best cases as a model and develop the coastal areas in a far more rational manner.

If we accept the premise that mankind will continue with the development of the coastal zone for its particular purposes, then we also have to accept the fact that this activity will have some impact on the marine environment. The real question then becomes not how do we preserve the entire coastal zone as we imagine it once was, but rather how do we develop the marine environment in our coastal zone so that it can be ecologically sustainable on a long-term basis. I believe there are many lessons to be drawn from our experience of terrestrial development. For example, for terrestrial food production, the bulk of it has generally evolved in areas that are conducive to high intensity agricultural methods. High intensity food production results in less land area used to produce a crop, better access to bulk transportation, more cost effectiveness and possibly less environmental damage. Note that this does not necessarily imply that "super" farms are better than "family" farms. Obviously, the better the agricultural practice fits in the natural environment of the region, the more sustainable it will be in the long term and the less intrusive the operation will be on the natural flora and fauna surrounding this production zone. Society has chosen this route of food production over time because it has been a good working model. In some cases, society has formally protected these naturally productive areas from other urban development by creating "agricultural land reserves".

Because of the natural characteristics of these growing areas, society has accepted the changes to the natural environment and the local impacts. We do not ask terrestrial farmers to ensure that they have a representative sampling of the various tree and plant species of the region growing throughout their fields or have a lot of vertical relief in the form of boulders and deadfalls to create habitat for other species. Instead, we encourage buffer areas, hedgerows, maintenance of wetlands and wildlife corridors. However, our present perception on how the marine environment should be managed and utilized is as a "natural habitat". In Canada, most marine development now is preceded by an "environmental impact assessment" to determine what species are at risk and what the potential impact of the development will be in a particular area. These are all credible goals that few would reasonably argue against, but are they really fulfilling our ultimate objectives for the sustainable development of our coastal zones? If we accept the notion that the course of development will reflect that seen in our terrestrial environments, then perhaps some of the early questions that we should be asking ourselves are not only whether or not the proposed marine development will have any impact on species in the area, but rather whether the development is in the right area to begin with? It is naive to believe that we can develop the coastal zone wherever we like and have no impact on the local populations. Therefore, it is imperative that we choose the sites of development carefully. Zoning is an issue that is being grappled with by a multitude of managers in a multitude of government organizations. In most cases, they are likely dealing with an incomplete knowledge-base on the dynamics of the marine systems they are trying to manage, as well as what the potential impact might be.

There is no escape from the implications of the above conclusion on the requirement for zoning in our marine systems. We need to have more information on how our coastal ecosystems work and to identify and monitor the main driving variables that control the local populations. As our need for management increases, the level and complexity of information needed increases in a nonlinear fashion. This is not a new conclusion as it has been recognized within the marine science community for decades, particularly in the light of fisheries management. In order to adequately understand the stock-recruitment relationship, the level of information required to manage these fish populations was far more than that justified by the value of the fishery that was being managed. However, the playing field is now changing. New stakeholders are now laying claim to the rights for development of the coastal zone whether it be for alternate methods of food production, for industrial resource extraction, for human recreation and housing, or for the establishment of marine protected areas (the marine equivalent of the national park system). With additional pressures being brought to bear on the system, our deadline to develop this understanding of the coastal process has now been moved up, whether we acknowledge it or not. Decisions will be made by managers, whether or not information is available. The probability of these being the right decisions will then depend on the intuition, luck and confidence of the manager. This is not a logical course to follow.

The only solution to this dilemma is plain and simple, old-fashioned, hard work. The "preservationist" path will not be enough to meet our long-term needs. We need to charge our universities and government biological departments to get back immediately to population-based research within the coastal zone to help us understand what is driving our marine biological communities. This should obviously extend further than the limited suite of commercial species that currently receive most of the attention. Resource managers from the federal to municipal level should aggressively feed directly into this research by formulating specific questions that they need answers for. The financial support for these initiatives should be driven from the highest levels of government knowing that this type of information is critical for their long-term decisions and that it will be a long-term process that needs to be started immediately. The potential implication of not understanding the systems we are trying to manage is a slow descent into chaos from the conflicting demands of the multi-user world and the collapse of our coastal populations from the "death of a thousand small cuts".

— Shawn Robinson

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(e-mail robinsonsm@mar.dfo-mpo.gc.ca)

The Life and Times of the "Myti" Mussel

Douglas McLeod

The impressive expansion in the global production of mussels in the past 50 years is primarily due to aquaculture output, which has increased 20-fold to over 1.3 million metric tons. Production is dominated by Asia and Europe, which exceed 90% of aggregate output. In international trade, Europe remains dominant, producing 50% of exports by value and 75% by volume. The main species is *Mytilis edulis,* although its overwhelming dominance has been eroded in recent years. The future prospects for expansion is for the rate of growth in production volume to slow. Although sale of fresh, live mussels will continue to be the mainstay, the strongest growth is expected to be in value-added products. Alternative development scenarios to the "bigger is better" vision of mussel farming need to be considered, along with a view of how to unlock market potential, improve commercial prospects for mussel farmers, and promote international collaboration and coordination.

Introduction

I'd like to thank the organising committee of the First International Mussel Forum, in particular Richard Gallant and Bob Johnston, as well as the sponsors of the event, for the honour of the invitation of delivering this inaugural Keynote Address. I hope and expect that the International Mussel Forum will come to be a regular fixture on the calendar of the international shellfish industry.

As well as speaking today as Chairman of the Association of Scottish Shellfish Growers (ASSG), I am also a representative from the Association Europeenne des Producteurs de Mollusques/European Mollusc Producers Association (AEPM/EMPA). The ASSG is a national trade association, but AEPM/EMPA is a recent innovation on the European shellfish scene. Because of widely differing national scales of production, environments and priorities, the European shellfish cultivation sector has historically lacked a common voice in Brussels. This void was filled in 1999, with the creation of AEPM/EMPA as a Community-wide organisation to represent the sector's interests in Brussels and to improve communication and dialogue with the European Commission.

Initial membership of this "association of associations", of which I had the honour of being the first president, includes trade associations from England and Wales, France, Greece, Ireland, Scotland and Spain, with an expectation of expansion to include additional representatives of Member States in the future. Nevertheless, the six founding members form a representative cross-section of the Community sector, including examples of large scale, mature industries as well as smaller, more recently developed industries, and both Atlantic and Mediterranean operations.

In addition, the combined production of EMPA national industries totals over 400 thousand metric tons (KT), close to two-thirds of the EU cultivated shellfish output. The Association is therefore a legitimate voice for the European-wide sector and enjoys the formal recognition as the Community-level representative for the industry.

The role of EMPA is to co-ordinate the views of industry and communicate them to the Commission, and to disseminate the views and proposals of the Commission to industry; and to protect and promote the best interests of the sector, directly and in alliance with others at the European level. EMPA expects to be the focus for industry representation, interaction and communication with the Commission, the Parliament and other European institutions in future discussions concerning direct sectoral issues and associated development of policies, including the implementation of ICZM, consolidation of Food Hygiene Directives, etc.

Global Mussel Industry

The main thrust of this presentation is at the level of the global mussel industry and I intend to commence with a review of recent developments.

Recent developments

Over the last 50 years, global mussel production has risen almost 10-fold, from 164 KT in 1950 to almost 1.6 million tons in the year 2000 (unless otherwise noted, the data source throughout is the United Nations Food and Agricultural Organization (FAO)). But within this overall success story there is a profound dichotomy of performance between the capture and cultivation sectors. While capture volumes have more than doubled, aquaculture output has expanded some 20-fold, from less than 100 KT to over 1.3 million tons.

The cultivation sector "took off" in the 1970s, but in my opinion the most impressive period for growth has been the 1980s. Although the "easiest" growth from the most sheltered and obvious culture sites had been achieved during the previous two decades, total output virtually doubled between 1980 and 1990.

Overall the contribution of cultivation to global mussel supplies rose from less than 40% to around 85% during the period, an impressive achievement. And there are no indications that the trend is likely to be reversed.

In light of the differing experiences between the two arms of the mussel production sector, it is perhaps important at this point to clarify the definitions of capture and cultivation. There is a continuum between the extremes of the public fishery and intensive culture; however, turning to the FAO, the term "aquaculture" has been defined as, in essence, requiring control over the stock and/or the growing environment, specifically intervention in the rearing process and legal ownership of the stock.

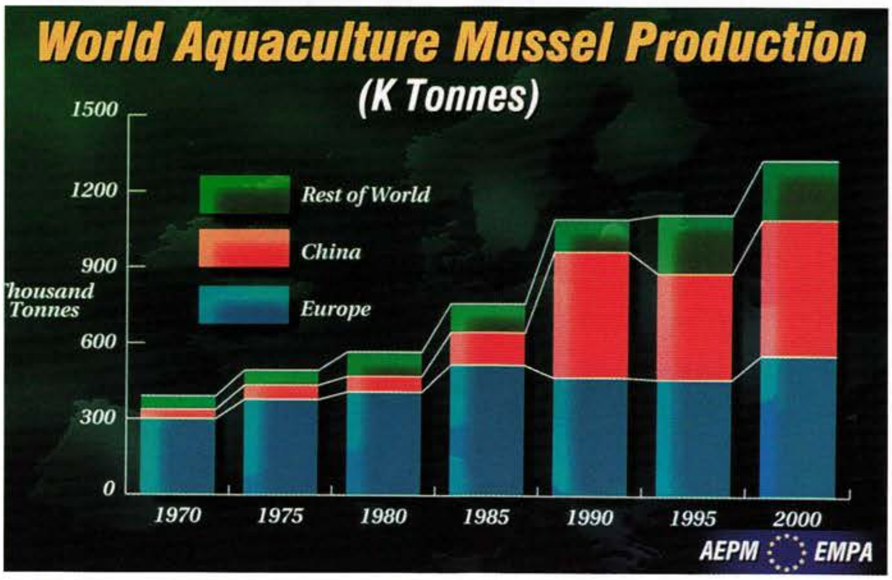
World mussel production can be portrayed as a two-horse race, between Europe and China

Mussel production data

Detailed data on aquaculture production of mussels has been assessed for the past 30 years, illustrated with statistical "snapshots" at 5-year intervals for the major producing regions, whilst remembering that individual country output can experience large swings between years, with changes of 50% up or down not unusual. Over the past three decades, aggregate production has more than trebled. Within this expansion the main storyline is the particularly strong growth in Asia, driven largely by developments in China. Despite a doubling in European volumes to 550 KT in 2000, production in Asia expanded dramatically from less than 100 KT to more than 600 KT, with China alone increasing from below 40 KT to over 534 KT.

Output from the rest of the world (RoW) has also increased steadily, from 54 KT to 235 KT, with the emergence since the late 1980s of some additional new players, namely Canada, New Zealand and Chile. Output from these countries expanded from marginal volumes in 1970 to a combined 120 KT by the turn of the century.

In recent years (1995–2000) a number of countries have performed impressively, with Chile increasing



production 4-fold, and Canada and Ireland more than doubling annual volumes. New Zealand has maintained steady growth, from 62 to 76 KT, while Malaysia has come from nowhere to reach some 10 KT. Korean production has exhibited some wild gyrations during the 1990s, starting the decade at 10 KT, rising to 75 KT in 1995, then crashing to 11 KT in 2000.

Turning these volumes into market share, there has clearly been a major sea change over the period, with Europe's share declining from 77% to 42%, China's contribution more than quadrupling from below 10% to over 40%, while RoW has largely maintained a share in the mid-teens, after reaching a peak of around 20% in 1995. Significantly, the non-Asian RoW, largely driven by New Zealand, Chile and Canada, has steadily increased its share from little more than 1% to some 9% by 2000.

Forecast for the mussel industry is for a greater emphasis on processed product

What has been constant is that at the global level, mussel production is dominated by Europe and Asia, with combined output from these two regions regularly and consistently exceeding 90% of aggregate output. However, within that dominance, there has been a major realignment of relative strength, with Asia's contribution rising from 18% to around 50%, largely as a result of China's expansion.

In summary, world mussel production can be portrayed as a two-horse race, between Europe and Asia. Indeed, as a result of its scale of production, I would argue that the race is essentially between Europe and China.

Turning away from aggregate volumes, the next question is: What species are we cultivating? The dominant species is clearly the "blue mussel" (*Mytilus edulis*), which expanded from 309 KT in 1970 to 860 KT in 2000. Nevertheless, production of "green mussels" has more than tripled over the period, from 50 KT to 168 KT, while production of "black mussels" has risen from 16 KT to 117 KT.

The earlier overwhelming dominance of the blue mussel (80%) has been somewhat eroded, declining to around two-thirds, while "green mussels" have maintained their share at around 13% (after a period of declining contribution during the 1980s); meanwhile the Mediterranean "black mussels" have increased share from 4% to around 10%.

Diversification, in terms of New Zealand "greenshell mussels", Chilean species and various other species, has increased from 3% to almost 14% of aggregate production. However, there is no doubt that if, as the international mussel community, we were to design a flag or logo, the colours should be based on a tripartite blue, green and black patchwork!

Turning to the value of the industry (with detailed data from 1985), the overall first-sale value of cultivated mussels rose from US$370 million in 1985 to US$550 million in 2000, with a clear dominance by the relatively high-value European industry, despite only marginal growth from US$335 million in 1985 to US$350 million by 2000. In contrast, the value of China's production rose rapidly from US$10 million in 1985 to US$105 million by the turn of the century, while RoW values quadrupled from US$25 million to US$100 million over the period.

In terms of share, the European contribution declined from 91% to 63%, a less dramatic erosion than in volume terms, while China gained share from 2% to 19%, a more rapid growth than the volumetric expansion, implying a rise in farmgate values.

The RoW share, which had maintained volumetric share, after the mid-1990s peak (15% to 17%), more than doubled in value contribution over the period, from 7% in 1985 to 18% by the year 2000, reflecting the expansion in relatively high priced supplies from New Zealand and Canada.

Production or first-sale prices vary widely around the world. Europe has traditionally been a high-value market, with prices generally averaging around US$650 per ton, although the data indicates a spike around 1990, when prices rose to an average of US$830 per ton. This average disguises a wide range of values, with for example UK prices rising consistently throughout the period from US$585/ton to over US$1,700/ton by 2000, while Spanish prices, which rose from US$650/ton in 1985 to US$1,000/ton in 1990, have exhibited a declining trend thereafter, to around US$350/ton by 2000.

Average prices for mussels in China remained stable at around US$70/ton until the mid-1990s, when they began to rise, reaching US$200/ton by 2000. RoW prices have risen consistently but unspectacularly over the period, from US$220/ton in 1985 to US$430/ton in 2000, although there was a spurt in the early 1990s with a one-third increase over the period 1990–95. That "spurt" was not reflected in prices for New Zealand and Canadian values, where the increase was less than 10% for the former and a decline of 12% for the latter. In fact, Canadian prices have declined over most of the period, from over US$1,200/ton in 1985 to an apparent stable "support" level around US$800/ton, perhaps initially reflecting rising production without supportive market development.

International trade

The next area for review is that of international trade, where aggregate exports have risen from 140 to 240 KT. European prominence is even more pronounced here, although again the trend over the period is for a consistent erosion of that position. European exports (including intra-European trade) rose from some 135 KT to around 180 KT by 2000, while RoW export volumes grew rapidly, from 5 KT to 45 KT over the period. China barely registered on the international trade data base until the late 1990s — nevertheless, from a standing start in 1990 China had achieved exports of some 15 KT by 2000.

In terms of shares, Europe's contribution declined from 97% to 75%. However, this decline was largely due to increasing trade from RoW, which rose from 3% of global exports to 18%, while China contributed some 6% by 2000.

Turning to export valuation, the total has expanded dramatically, from US$65 million to over US$340 million. Europe's contribution has risen from over US$50 million to some US$170 million by 2000, while China achieved a level of close to US$20 million. However the headline story is the expansion of RoW export values from US$12 million to US$150 million of the global total.

In terms of share, Europe's contribution eroded from 81% to 50%, despite the strong expansion, reflecting the emergence of China (5%) and the dramatic growth in RoW values from 19% to 45%.

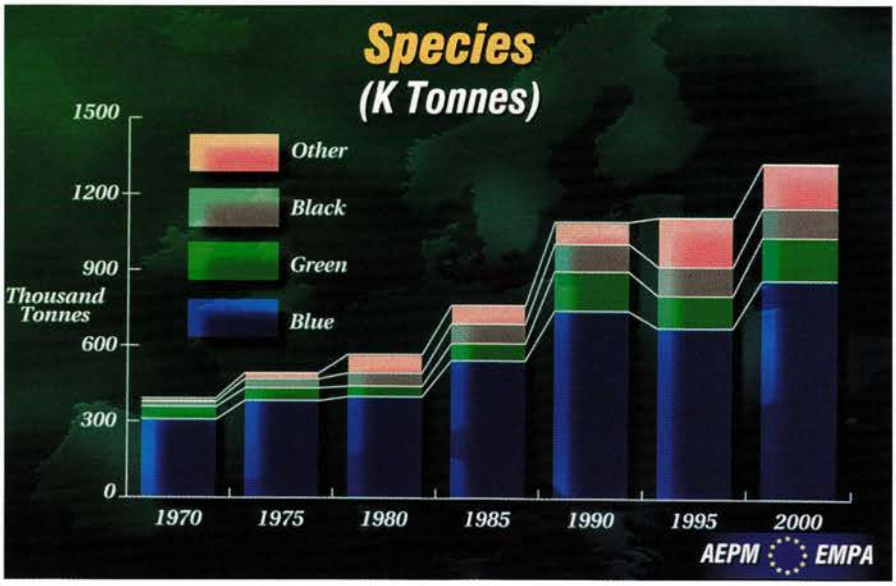
So international trade in mussels is certainly growing, not simply in gross volume terms, but also in terms of "export integration", that is, exports as a percentage of domestic supply (local production plus imports). We see increases for Europe, from 14% in 1985 to 35% by 2000, and from 27% to 58% for RoW. Exports, largely in the form of processed products, are a major driver for the development of mussel aquaculture around the globe.

The rationale for this process is further illustrated by consideration of export prices and their relationship with domestic values in recent years. Export prices in Europe have risen to peaks of US$1,555/ton in the mid-1990s, before dropping back to around US$1,000 by 2000, with a similar pattern for average export prices from China during the late 1990s.

RoW exports have maintained higher average values (reflecting a significantly lower level of fresh trade than in Europe), stabilising around US$3,500/ton during the 1990s. Import prices have tended to be significantly lower, particularly in the non-European areas, reflecting the predominant role of processing in converting low fresh value to high value ready-to-eat products in these markets.

This relationship encourages "processing" nations to import volumes of mussels for export if their domestic industry fails to produce sufficient supplies. This applies to both European countries (e.g., the UK), as well as other exporters, particularly when there are significant "sunk" investments in processing facilities.

Assessing the export value ratio (EVR)—export prices as % of domestic production prices—it becomes clear that even for European producers there is a positive economic incentive to export, as long as the gross margin is sufficient to cover costs of processing and profit, which in all cases appears to be the case. In the non-European regions, an EVR of around 8 appears to be a profitable and long-term sustainable



level. There are times when the margin rises significantly, but inevitably competition drives the margin down towards the long-term sustainable level.

Characteristics of the industry

In concluding this review of the recent history of the international mussel sector I suggest there are a number of distinctive characteristics of this industry:

- The dynamo of the global mussel industry is the cultivation sector;
- Annual production can vary significantly, indicating that, as an industry, it is still reliant on natural processes;
- The aquaculture sector is essentially bi-polar, with two producing regions of broadly similar scale, namely Europe and China, at around 500–600 KT per annum each;
- In terms of international trade, Europe remains dominant (50% of exports by value, 75% by volume);
- The economic benefit from exporting (processed) mussels remains strongly positive.

The major problem facing the mussel industry—whether in the Atlantic Ocean or the Yellow Sea—is water quality

A further characteristic of the industry is its global nature (exemplified by this Forum!), with common features repeated around the world—after all, a longline is a longline! But every nation puts a slightly different spin on the techniques and technology.

European Mussel Industry

The major position of the European industry in the global mussel industry gives legitimacy to my wish to focus on the profile or characteristics of the overall European scene—other presenters will address the situation in specific countries, both in Europe and elsewhere, but I intend to remain at the international level.

The overall European shellfish industry was analysed in 2000 for the European Commission by consultants MacAlister Elliott & Partners (MEP). Although a number of national organisations, most notably in France and Spain, have queried the accuracy of some of the data, the report provides a useful "baseline" of data presented on a comparable basis across the EU. The characteristics of the sector can be summarised as follows :

- The Report concluded that the production of cultivated shellfish (1997) totalled some 665 KT:
  - The data indicate that this volume is dominated by mussels, which, at 515 KT, represented about three-quarters of European shellfish output;
  - Oyster production (*Ostrea edulis* and *Crassostrea gigas*) reached some 100 KT, 15% of total EU cultivated shellfish output;
  - The third group assessed, clams, accounted for around 50 KT.
- With a first-sale value of around 600 million (euros), cultivated shellfish was worth around 30% of the overall 2 billion European aquaculture business:
  - Although still the dominant species, in value terms the importance of mussels declined to 47% of the total, some 270 million;
  - First-sale values for oysters and clams totalled around 150 million for each species (26 to 28%).
  - Average prices ranged from just over 500 per ton for mussels—ranging from 400 for dredged product to 1600 for mussels grown in suspended cultivation in Scotland—to 3,000 per ton for clams.
  - There is an equally skewed distribution of the location of activity across the Union. Shellfish production is geographically extremely concentrated, with 73% attributable to only three countries: Spain, the leader, with 198 KT or 30% of the total, followed by Italy with 143 KT (22%) and France at 141 KT (21%).
- There is a similar pattern of concentration at the individual species level :
  - *Mussels:* 75% from the top three producers, with Spain at 189 KT (NB *'Mexillon de Galicia'* estimate production at over 250 KT), Italy at 103 KT and The Netherlands at 93 KT;
  - *Oysters:* 94% from the top three producers, with France at 87 KT (the *'Comite National de la Cochyliculture'* estimate is 140 KT), followed at a significant distance by Ireland at 4.4 KT and Spain at 3.4 KT);
  - *Clams:* 96% from the top three producers (Italy 40 KT, Spain 5.6 KT and Portugal 3.3 KT).

In addition to these production and value parameters, a further particularly significant socioeconomic attribute of shellfish farming, reflecting the relatively "low tech" nature of operations, is the contribution it makes to employment. The sector is calculated to generate around 20,000 full-time equivalent jobs in the production segment alone, over 50% of total direct employment in the European aquaculture industry.

The income generation opportunities created by shellfish cultivation have major socioeconomic importance, as they are typically located in remote coastal regions where alternative employment is so often sadly lacking.

Focusing more closely on the mussel sub-sector, trends in production over the decade of the 1990s indicate that, to a significant extent, where Spain goes, Europe goes! Aggregate European production has risen from 460 to 550 KT over the decade, with a decline to a low point of around 370 KT in 1993 followed by recovery to an interim plateau of 500 KT in 1996/97 and further growth to a second apparent plateau of some 600 KT in 1998/99. The overall volumes can be analysed in terms of two groups of countries :

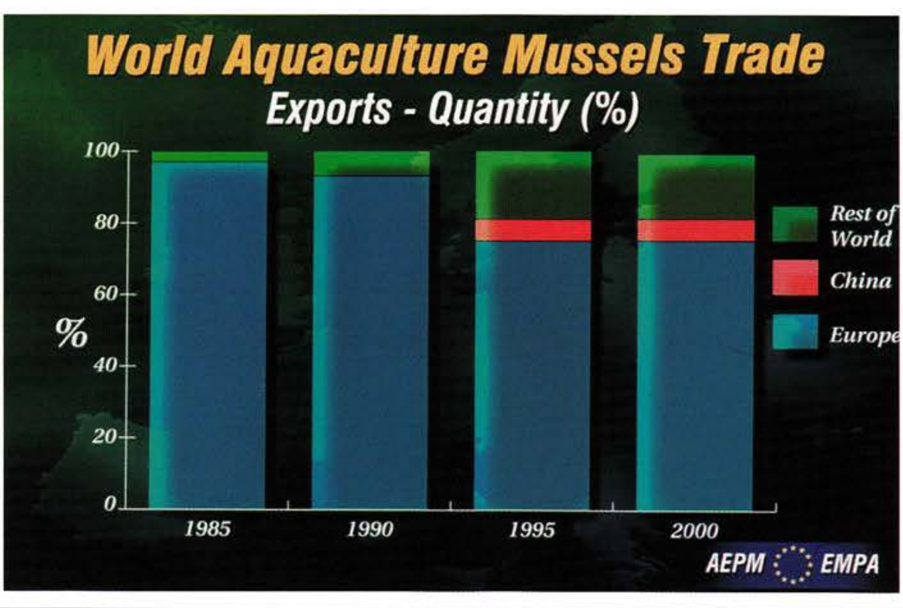
- *The "majors"*: Spain, Italy, the Netherlands and France produced around 85% to 90% of Euro-mussels during this period, an overwhelming dominance! But this is not to say that volumes were stable or consistent. In Spain, production oscillated between 140 and 260 KT (the latter figure appears to represent "nominal capacity" output at the moment). Apart from the disastrous year of 1993, when production slumped to around 90 KT—so clearly mussel cultivation remains subject to natural variation—Italian production has risen from a plateau of around 80 KT to a new level of some 130 KT (excluding their poor year of 70 KT in 1994). The mature industry in the Netherlands appears to have a nominal output level of around 100 KT, with some significant annual variations, including a 50% slump in 1992 and a peak of 113 KT in 1998. Reported French output appears remarkably stable in comparison, with only relatively minor variations from around 60 KT per year;
- *Others*: Germany and Greece are the two medium-sized industries that have improved their production performance over the period, from 25 to 55 KT, although again there have been significant annual variations. In Ireland, production has risen to almost 26 KT in 2000. The UK has also enjoyed growth, but the industry remains small scale, at 11 KT in 2000, while Sweden reported marginal volumes of cultivated mussels (Danish production is classified as "capture" fishery supplies).

In summary, the two dominating characteristics of the European mussel sector over this decade are:

- The strong long-term growth in total output, with a 40% increase (+ 180 KT) in incremental volumes which have been absorbed by the market without any major price decline (current euros);
- The significant volatility in production between years, with swings of 50% not uncommon.

Looking to the future, I expect production in the mature, large scale producing nations (Spain, France, Netherlands, Italy) to broadly maintain current or marginally higher levels—the main source for incremental output, at least in the short to medium term, will be from the peripheral nations, including Ireland, UK, Norway, Iceland, Portugal and Greece.

The market for mussels and other shellfish in Europe varies in intensity and format between the different nations. On the basis of data from the UK Seafish Industry Authority, per capita consumption of fresh mussels ranges from 2.75 kg/year in Belgium through 0.7 kg/year in France to around 100 gram/year in the UK. In France the market for bivalve shellfish is dom-



inated by fresh sales (some 93%), and the story is broadly similar in Italy (83%).

However, in Europe's largest market, Spain, we see a different market profile, with per capita consumption of fresh mussels at 1.5 kg/year, significantly below the equivalents for tinned (2.3 kg) and frozen (1.7 kg) products. This difference reflects both a different trans-Pyrenean culinary tradition and the modern trend towards convenience, processed food products. The consumer increasingly places a premium on meal preparation time and fresh shellfish is increasingly perceived to impose a relatively high demand on time.

Only time will tell whether the rest of the European market will follow the Spanish example, but my personal view is that the Iberian trend will become the European norm, and that the future for the industry is for a greater emphasis on processed products.

The promotional leaflet for Scottish shellfish—based on emphasising the freshness of the products—has been replaced by a marketing focus on prepared dishes, such as mussels in various sauces located in the chill cabinet, rather than on living in-shell mussels on the fish counter.

In conclusion, improving on the limited "Business As Usual" growth in consumption projected by the MEP report will require a continued focus on the traditional core markets, which is where the volume markets are located, combined with a determined effort to attract a new generation of consumers. In contrast, future production growth is likely to be concentrated in new, peripheral producing areas, leading to increased intra-European trade.

But I forecast that much of this increase will be in the form of processed product, due to shifts in consumer preferences, the cost of transporting "shell", and the perceived disease risks of transporting live shellfish.

Future Trends

Returning to the global picture, and considering possible future trends in the global industry as we enter a new century, can we summarise with a confrontational image of: "In the blue corner, Europe; In the red corner, China"?

Is it inevitable to forecast a competitive clash between the mature and strong "Euro-mussel", with an established major role in international trade, and the vibrant, dynamic, "new kid on the block", the "Yuan-mussel" from China? In my opinion, the answer is a resounding "No", particularly if producers re-focus effort away from simple volume increases and onto market development, emphasising quality and using innovative products to persuade consumers to defect from poultry, beef, lamb and pork in the "protein war".

Part of the characteristic of globalisation or commonality I mentioned earlier is that the major problem facing the mussel industry is the same whether it's the Atlantic Ocean or the Yellow Sea that's being discussed, namely water quality and in particular the impact of marine biotoxins. Improved collaboration in scientific research as well as management and mitigation techniques across the global community, both industry and science, will be essential to help the sector justify its claims of quality and continue to expand.

The extent and scale of impact of the various biotoxins in Europe is well documented, with PSP being recorded across the continent, and DSP close behind in geographic spread. ASP has been less widely reported, but its impact in Spain, Ireland and Scotland makes it one of the most economically destructive biotoxins on record. AZP has to date been apparently limited to Ireland, although there are those who remain convinced that if you look for biotoxins, you'll inevitably find them!

I continue to be concerned that the scientific community, in its natural desire to pursue research into shellfish issues, is generating a "feeding frenzy" amongst food safety regulators, who are already suffering post-BSE (bovine spongiform encephalopathy) paranoia, supplying them with additional reasons for incremental restrictions and constraints on the bivalve producers of the world.

At a recent conference, the first morning session was dedicated to novel threats to public health and succeeded in driving me to melancholic reflections on the depressing outlook for the shellfish sector as well as musing on the apparently profound divide between the industry, the scientific community and those with responsibility for protecting consumer health.

This additional example of the threat to the industry from biotoxins later evaporated, as happily it became clear that once a responsible risk assessment analysis of the novel toxin was carried out, the true risk to consumers was negligible. But there is also a need for credible cost-benefit analyses to be carried out when so-called consumer-protection measures are introduced, as heavy-handed regulation can have a major impact on peoples lives out there in the real world, in the form of the destruction of jobs, as well as driving operators into a "grey economy" where standards are in effect lower than before the introduction of more restrictive criteria.

There already are tools available to help manage the threat of marine biotoxins, ranging from the use of real time satellite images of blooms (allowing targeted sampling, an approach successfully adopted in Galicia, Spain) to the development of linked detailed models, enabling optimal positioning of culture units for both growth and bloom avoidance. These tools are expensive, however, and it is essential for the industry to lobby government for adequate levels of investment into these instruments, as opposed to the cheap and easy option of shutting the industry down whenever there are biotoxin problems.

Within the ranks of industry itself a second divide is visible, in differing visions of the future direction for the industry. There are many who insist that "size matters", that the way forward is basically a question of scale, that the industry must escape from the tyranny of the small family unit and, following the example of terrestrial farming, embrace large scale operations. Their arguments are:

- That this is the only way to significantly reduce unit costs, thereby enabling improved competitiveness in the "protein war" and/or enhanced profit margins;
- Such an approach is not resource constrained, as the primary production source of algal feed is massively under utilised at the moment, and mussels are a highly efficient mechanism for converting such vegetable matter to protein;
- Technological advances have also made it possible to scale up production units efficiently;
- The potential market is virtually limitless, as mussel meats are the perfect flexible product—boneless, skinless, infinitely adaptable to different culinary traditions and flavourings.

However, there is at least one alternative vision for future development, one based on:

- Investment in targeted market development and improvement in profitability rather than volume for the sake of volume;
- The identification of niche markets and the phased expansion of these sectors through focussed marketing efforts and innovative processed products.
- This strategy recognises the dangers of a production driven industry and advocates a market-led strategic approach, aiming to break the apparently inevitable boom and bust "hog cycle" which traditionally affects commodity agriculture products and has most recently been illustrated in the farmed salmon and sea bass/sea bream industries.

Time will tell which philosophy will win out during future decades!

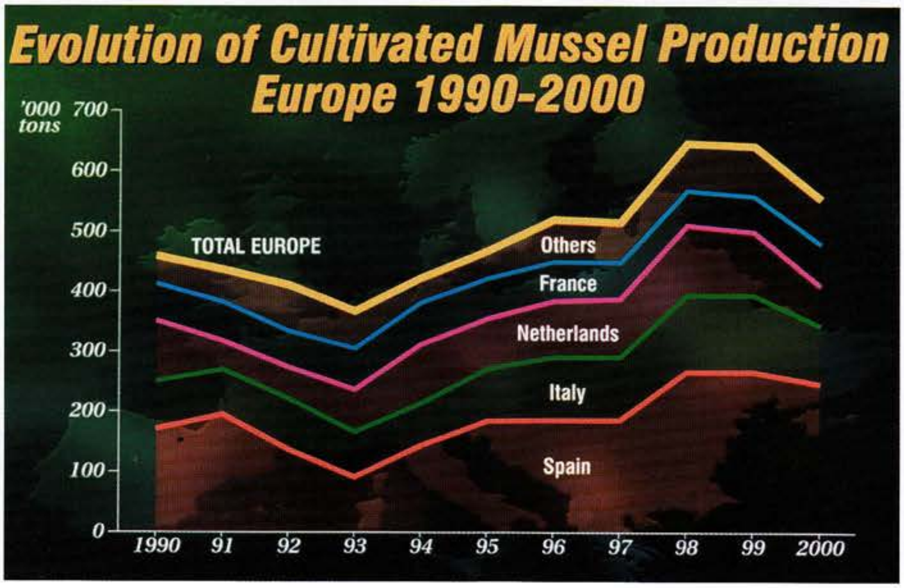
Concluding Remarks

Most presentations that review history and consider the future conclude with forecasts of variables such as supply and demand—but I will leave such comments to our country speakers, who will have significantly greater knowledge of their individual industries than I, and focus my concluding remarks on my expectations for the characteristics of the international mussel industry.

In essence I see both "upside opportunities" and "downside challenges" for the industry in future years:

- The "upside" potential reflects the significantly more positive image and outlook for shellfish in comparison with other food sectors, as mentioned earlier, and the way in which technology, market opportunities, and the great untapped resource of algae are coming together like pieces of a jigsaw;
- "Downside" difficulties include the treat from marine biotoxins and the impact of misdirected and over zealous regulation.

Other characteristics that I expect for the future industry include:



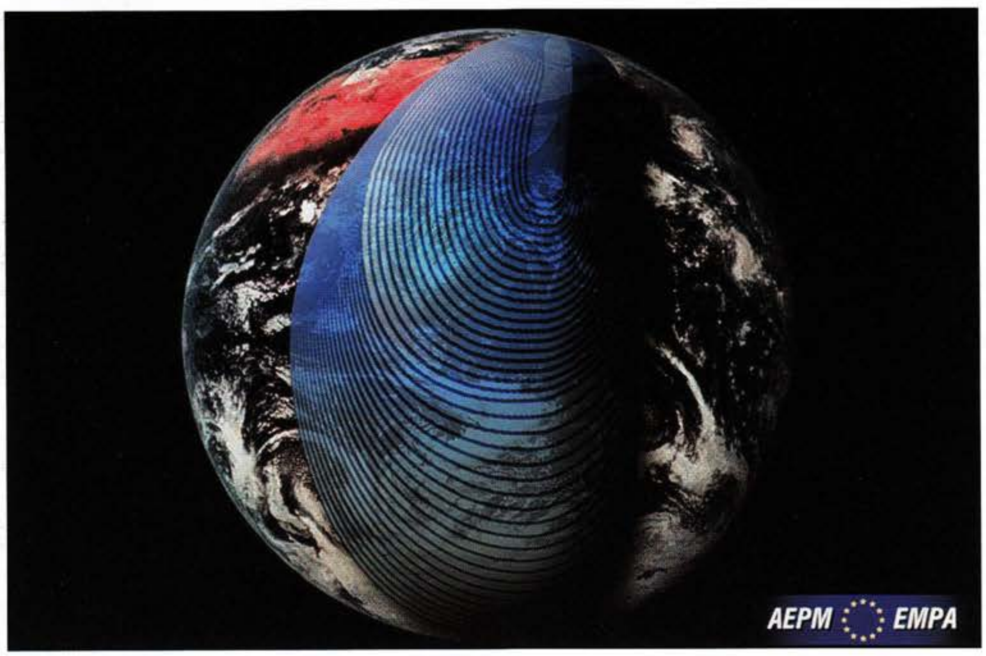
- Continued expansion in global production volumes, although the rate of growth is likely to slow from the levels experienced in the recent past.
- Fresh, live sales will remain the mainstay of global sales, with strong growth in domestic sales and commodity deals with processing operators converting product for export.
- There will be strong expansion in sophisticated, segmented markets, particularly in Europe and North America, requiring innovation in product type, presentation and marketing, and enjoying healthy profit margins;
- The march of technology will enable the creation of larger volume sites in specific and appropriate locations, stimulating a step change in third party investment in mussel farming, but such operations will remain the exception;
- Globally I expect there will be an ever greater focus on associated health risks, both real and perceived, including biotoxins, chemicals (PAHs, dioxins, PCBs, "gender benders", etc), heavy metals, bacteria and viruses. While outside interests will react by demanding more intensive levels of environmental monitoring and shellfish analysis, the industry will respond through enhanced investment in research and development of more effective depuration and de-toxification, whilst demanding stricter discharge conditions and more stringent implementation of "the polluter pays" principle.
- International trade in mussels will continue to expand, driven by market requirements and production growth, supported by World Trade Organization (WTO) de-regulation and the emergence of China as a major exporter, certainly regionally and potentially to the more distant European and North American markets, once the infrastructure has caught up with import requirements.

But whatever the accuracy of my predictions for the future of the international mussel industry, there is no doubt in my mind that we are operating in one of the most exciting sectors in business—just compare our prospects and problems with other food producers! Across the range, from beef and poultry through milk, cheese and eggs, to sheep meat and salmon, primary producers are struggling to persuade consumers that their products aren't really life threatening—all we have to worry about are biotoxins and an over-enthusiastic "food police"!

I am aware that in the past I have been castigated by some colleagues as an unredeemable optimist—but I believe my positive views reflect a reality, not a "rose-coloured glasses" vision.

And perhaps its no coincidence that the most widely cultivated mussel and Planet Earth share the same colour. I believe the industry can look forward with great confidence to this new century, to progress towards "Planet Mytilus", with a great catch phrase:

"The Future's Blue,
The Future's Mussel Shaped"



The French Mussel Industry: Present Status and Perspectives

Jean Prou and Philippe Goulletquer

The French mussel industry produces around 60,000 metric tons on a yearly basis using two common species: *Mytilus edulis*, which is widely distributed along the Atlantic coastline, and *Mytilus galloprovincialis*, distributed mainly on Mediterranean shores. This production represents only half of the yearly consumption of mussels in France, leading to large imports from Spain and the Netherlands. Most imports occur between September and March, when the Atlantic production is reduced because of low meat quality due to spawning events. Although a public mussel fishery still exists, most production is based upon 3 culture techniques: on-bottom culture, longline and suspended culture, and bouchot-type culture, with the latter being developed in the 13th century. Annual landings from the public fishery are highly variable because of irregular spat recruitment. Presently, more than 1600 km of bouchots are distributed along the coastline, yielding around 55,000 t of mussels. On-bottom culture, a traditional activity, is limited and yields around 3000 t. Harvests from longline culture have significantly increased in the last 10 years, showing various degrees of success depending on the geographic location. This technique allows development offshore, far away from any pollutant source. Suspended culture has been successfully used to compensate for the irregular spat settlement within the intertidal area, as well as to expand marketing activity and increase growth rates. In the near future, the mussel industry will likely face several challenges, including increased sanitary regulations at the French and EU levels. This could result in further off-shore development, but might lead to space conflicts with other users (e.g., tourism, fisheries). To address that matter, Integrated Coastal Zone Management plans (ICZM) are currently under development in several Atlantic traditional rearing areas. The issues of product quality and labelling, such as geographic identification for marketing purposes, are among the top priorities for the mussel industry.

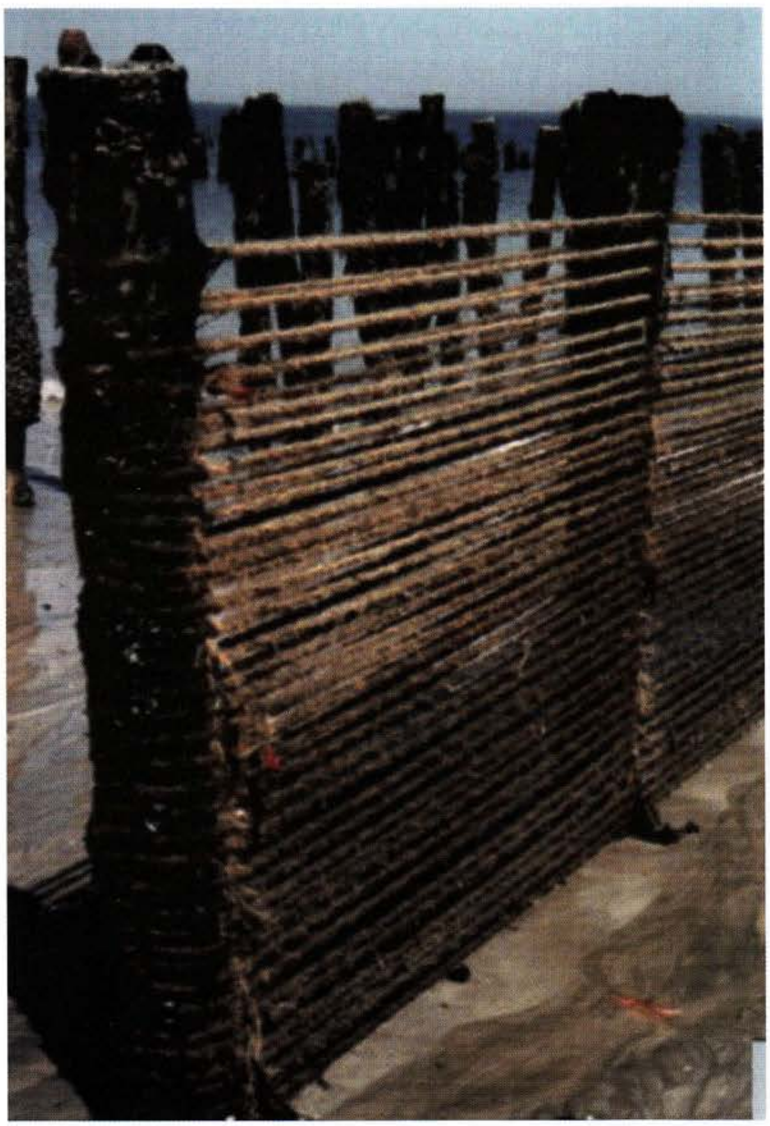
History of the French Mussel Industry

Mussel production in France involves two common species: *Mytilus edulis* is widely distributed along the English Channel to the southwest coastline of France, and *Mytilus galloprovincialis* is mainly distributed on Mediterranean shores. This wide distribution of mussels favored extensive fishing activity until the 19th century.

Mussel culture methods have been used in France since the 13th century, but only in one location in the southwest of France. According to legend, the origin of "bouchot" is attributed to an Irishman who was shipwrecked on the Charente coast in 1235. Sole survivor of this disaster, Patrick Walton stretched out nets at low tide to catch fish. He noticed that mussels attached themselves to the wooden stakes on which the nets were stretched. He then had the idea to plant stakes in a line to harvest mussels and the first "bouchot" was born. This technique, well adapted to large intertidal mud flats, strengthened the development of the blue mussel industry in France. After the Second World War, the "bouchot" technique expanded to other intertidal sites, particularly along the Brittany and Normandy shores. Recently, off-shore cultivation of *Mytilus edulis* has developed in protected areas such as the Charentais Sounds on the Atlantic coastline.

Mytilus galloprovincialis has been cultivated since 1925 in Mediterranean lagoons, mainly in the Bouzigues area located in Thau lagoon. Suspended culture on ropes is currently used. More recently, leases in the open ocean have permitted further development of the industry. However, predation of mussels by fish has recently impacted the longline production of mussels in this area.

The French mussel industry produces around 60,000 metric tons on a yearly basis. Normandy (44%) is now the main producing area, followed by Britanny (25%), Vendée-Charente (18%) and the Mediterranean (13%). Around 1600 km of "bouchots" represent 95% of the production. On-bottom culture (2000–3000 t) is mainly located in the Bay of Brest, Pas-de Calais and South Brittany shorelines. Longlines are located along the Mediterranean coastline as well as in Vendée-Charente. Landings from the public fishery are highly variable because of irregular spat recruitment and range between 10,000 and 50,000 t. The overall production represents an exchange value reaching 100 million (US$105 million).



Spat collecting on coconut fiber ropes

Growing and Processing Technology

Bouchot culture

Within intertidal areas, a typical spat collecting unit is made of one or two rows of 40 wooden poles (spat collecting "bouchot") on which 3000 meters of coconut fiber ropes are deployed. The density of rope is increased up to 5000 meters when the culture time is concomitantly reduced. On off-shore longlines, 500-m long ropes are wound on wrought iron rectangular frames. Spat collection occurs between March and June on the Atlantic coast and all year long in the Mediterranean Sea with peaks occurring in the spring and fall. Spat collection on off-shore platforms provides a better and more uniform yield compared to intertidal areas. Exposure of spat to air during ebb tide reduces growth and could be responsible for mortalities if extreme conditions are encountered (dry wind, thermal stress, etc). On the Brittany and Normandy shorelines, natural spat collection is insufficient to ensure a viable industry, so ropes with spat attached are therefore imported from the Vendée-Charente site.

Two months after spat fall, ropes and the attached spat are wound around large vertical poles (bouchots) in the intertidal zone. A mesh netting is used to cover the mussels to prevent them from being detached and lost, or preyed upon. In order to optimize spat densities during early development, mussel farmers thin the spat and prepare tubes of seed called "boudins". These cotton nets are wound around poles or suspended longlines.

Each pole is 4 to 7 m long, 15 to 25 cm in diameter, and protrudes 2 to 3 m above the bed. Several wood types are currently being used, including pine, oak and, more recently, squared Brazilian hardwood. Recycled plastic tubes are currently under evaluation. Bouchot structures vary between rearing areas. Generally, one or two rows of poles are spaced 25 m apart. The length of the rows and the numbers of poles used depends on the regulations in each area. The rearing density is adjusted to suit the carrying capacity of the area.

Harvesting begins as soon as the mussels reach the 40-mm marketable length, usually after a 12- to 15-month rearing period. One pole produces between 25 and 60 kg live weight of mussels per rearing cycle.[1] Mussels grown on bouchot poles are harvested by hand or, more often, using hydraulic fishing equipment that removes the entire population of mussels at one time. A cylinder is lowered to the bottom of the pole, closed and pulled up, and the mussels are dumped on the boat to be washed, graded, weighed, and packaged in 15- to 25-kg bags. Undersized mussels are transferred to mesh tubes that are reattached in the field around the growing poles. Amphibious vehicles currently are used in intertidal areas to maximize working time.

On-bottom culture

The on-bottom culture technique is based on transferring mussels from natural beds with high densities to culture plots where the density is reduced to improve growth and fattening, and to control predation. One-year-old mussels are dredged on wild mussel beds, then taken to the culture plots where they are deployed at a density ranging from 25 to 30 t per hectare. This process is carried out in spring and early summer. The rearing cycle lasts 14 to 24 months.

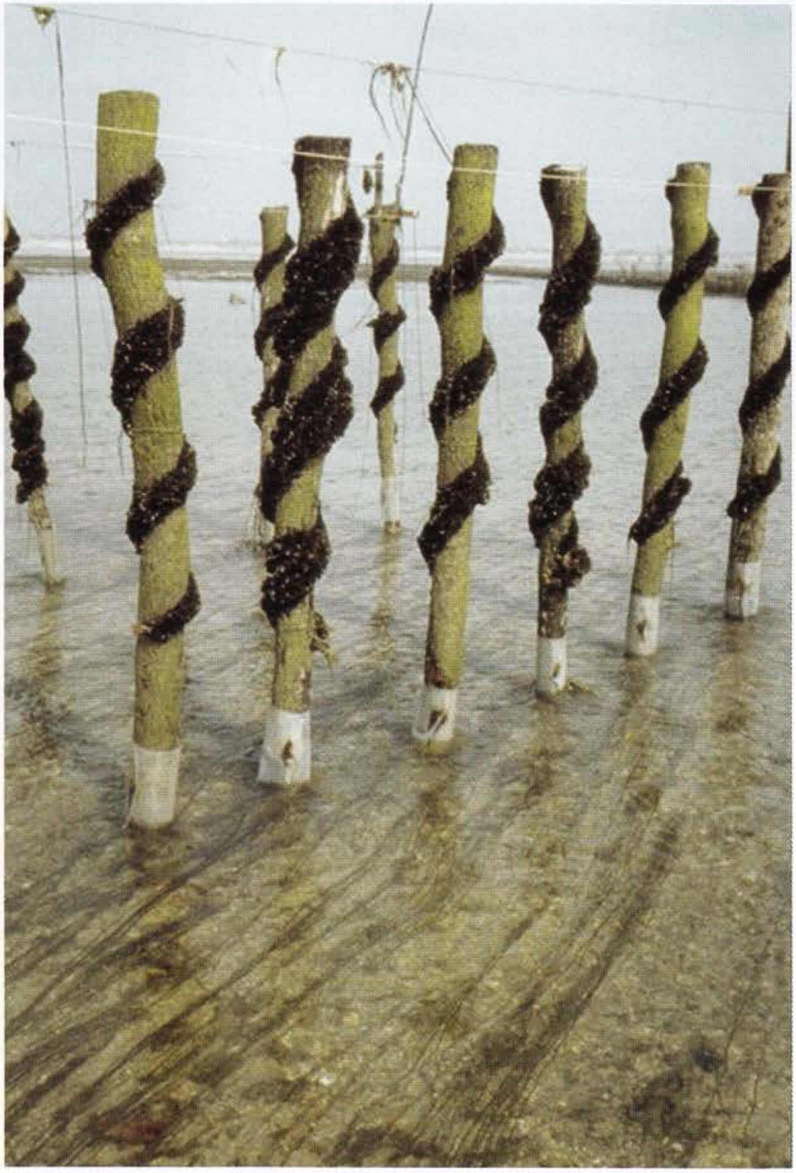
Longline culture and suspended culture

In the Thau lagoon, off-bottom culture is based upon fixed suspended structures (rafts) similar to those used for oyster culture. Seed is transplanted into plastic mesh tubes and hung vertically from the fixed tables.

On the Atlantic coast, the reduced availability of intertidal areas for mussel culture led to the development of longline culture methods. The first trials were carried out in the Pertuis Breton during the 1960s using raft techniques.[2] New subsurface longlines have been recently developed to resist storms and wake effects along the Atlantic coastline and offshore in the Mediterranean Sea. Floats are connected together with horizontal lines that support a large number of vertical ropes where mussels are grown. Annual production rates reach 18 to 20 t per hectare.

The public fishery

Compared to landings in previous centuries, the mussel fishery in France is a declining activity. The Barfleur area natural bed, located in Normandy, is one



Tubes of seed (boudins) wound around "bouchot" poles

of the last but most exploited beds. Around 65 fishermen are licensed for a total annual catch of about 8000 t. Every year, a stock assessment gives estimates of the quantity of mussels that can be fished without damage to the juveniles. Dredging is authorized, but the activity is highly regulated with controls on the daily catch per fisherman, dredge size, and fishing time. In the Bay of Bourgneuf (Loire estuary), oyster culture predominates and mussel fishermen are viewed as competitors because access to mussel beds is free, without license or regulations. Dredged mussels are generally transferred to leasing grounds in Brittany or are reared locally on bouchot. In other traditional areas, such as the Charente Maritime (Atlantic southwest), the fishery is based upon regulated access. No reliable statistics exist.

Comparing growth performance

Mussels cultured using longlines and bouchot techniques show different growth patterns. Submersion time, current pattern and trophic resources such as phytoplankton and turbidity are responsible for the higher growth performance recorded for mussels grown on longlines. By using this technique, marketable size can be reached after 10 months, compared to 14 months for the bouchot culture type. In both cases, the growth rate is higher during spring when the phytoplankton blooms occur.

The market size of *Mytilus edulis* and *M. galloprovincialis* is different. In the Mediterranean, the mean market weight of *M. galloprovincialis* is about 26 g, lower than the market weight of Spanish mussels. For bouchot mussels, the mean weight is 10.4 g, less than mussels produced in the Netherlands.[3]

Market

Marketing of mussels is based upon species peculiarities. Since *M. edulis* spawns in the spring, the condition index and meat quality are low between March and May. Therefore, the national production is mainly marketed from June to January. To balance supply and demand, around 60,000 t of cultured mussels are imported each year. Mussels are imported from Spain throughout the year, imports from Northern Europe (Ireland, Great Britain) occur from January to April, and mussels are imported from the Netherlands from September to April.[4]

Mediterranean production is commercialized all year round since no major seasonal spawning event occurs. Importations from Italy occur from April to July. From a geographic point of view, the market is also well defined with each producing area having a well specified sphere of influence.

A strong demand for national products and especially for the "bouchot" mussels exists. The demand is reflected in the difference in the retail price of around 2.5 euros/kg for domestically-produced mussels compared to 1.7 to 2.1 euros/kg for imported mussels.

In France, households represent 65% of the total consumption of shellfish, principally oysters and mussels. There is demand for fresh mussels in about 40% of French households, which are characterized by a 2-person lower or middle class family in the 50- to 64-year-old age class. About 33% of the retail household purchases are made at specialized outlets. "Hypermarkets" (55% of the purchases) are leading and tend to take the place of wholesalers for mussel commercialization.

In 2002, 32,879 t of mussels were consumed outside of households and in non-collective restaurants: 82% of the mussels were consumed fresh and only 18% had been frozen; 87% were consumed in the shell, compared to 13% prepared without the shell.[5]

Mussel Farmers Organizations

The French mussel industry includes more than 1000 farms which usually produce and also market their products. Most of the farms (70%) are family-size companies with a mean production of about 52 metric tons.[6]

The National Shellfish Committee (CNC) is the national industry body of French shellfish farmers. It is the compulsory stakeholder for all decisions and regulations related to shellfish management. French rearing areas are spatially divided into 7 Regional Shellfish Committees (SRC's). Under the supervision of the Ministry of Agriculture and Fishery, these committees are authorized to collect professional taxes. More recently, Organizations of Producers (OP's), recognized at the EU level, have been established and are responsible for marketing initiatives, as well as advertising campaigns. SRC's are in charge of quality issues, certification processes, and industry development.

Sanitary Control

Since the French shellfish market is based mainly on raw and fresh products, it is particularly important to protect the public from eating polluted or unhealthy products.

Microbiological aspects

Shellfish producing areas are divided into 4 classes according to seawater sanitary conditions. Class A zones permit cultivation or fishing and marketing without depuration. In Class B zones, mussels must

Hydraulic fishing equipment

be depurated either in a depuration plant or farm installation under agreement before marketing. Cleaning of mussels in specialized depuration plants is necessary for class C zones. Shellfish fishing and exploitation are forbidden in Class D areas.

Classification of areas is done after a zoning study based on shellfish analysis for fecal contamination. For example, A zones must satisfy 2 conditions. The first concerns fecal coliform concentrations: more than 90% of counts on a 100-g flesh sample must show MPN (most probable number) values lower than 300; one value larger than 1000 is sufficient to reject the A classification. The second concerns mean concentration of heavy metals per kilogram of wet flesh (0.5 mg for mercury; 2 mg for cadmium; 2 mg for lead).[7] Sanitary agreements of farm installations are given by both the Veterinary Office (sanitary) and Maritime Affairs (State legislation). Finally, products are controlled by the Veterinary Office at each step of the marketing process (packaging, transport, dealers). There are regulations concerning fecal coliform concentrations (300/100g wet flesh) and the presence of salmonella per 25 g wet flesh.[8] Furthermore, the shellfish industry organizes its sanitary controls on their own products to demonstrate and guarantee sanitary quality.

"REMI", conducted by IFREMER, is a Microbiological Monitoring Network.[9] Three hundred and eighty-five sites are sampled on a monthly or quarterly basis depending on the sanitary conditions. This national network has two objectives: providing data for the zone classifications and detecting abnormal concentrations. Micropollutants are also of concern in establishing the zoning. Regulations focusing on heavy metals, for example, have drastically changed recently and the legal threshold is now half of the previous level.

Since 1974, heavy metals, pesticides and hydrocarbons levels have been monitored by the Coastal Environment Monitoring Network (RNO). Forty-three sites are surveyed four times a year.[10]

The presence of phytotoxins in mussels is also of concern for sanitary control. In 1984, a Phytoplanktonic Monitoring Network (REPHY) was implemented in French coastal waters.[11] Every two weeks, 62 sites are sampled for estimation of phytoplanktonic cell counts. In high-risk areas or seasons, weekly samples on up to 133 sites are collected and analyzed. If a bloom occurs, shellfish are also collected for analysis of phycotoxins. Regulations give the following values :

PSP: less than 80 µg /100 g wet flesh
DSP: negative results with 24-h mouse bioassay
ASP: less than 20 µg domoic acid/g wet flesh (HPLC method).

Although so far not detected in French waters, AZP is part of the regular monitoring according to EU regulations. When a bloom occurs and tests are positive, the area is closed by state officials. Shellfish sales are stopped until two negative tests (i.e., two consecutive weeks) are reported.

The French mussel industry is systematically striving to maintain an A classification for the mussel rearing areas. Since no inland facilities for mussel depuration have been developed due to resulting summer mortalities, a B classification leads to a halt in production and marketing. By way of example, several events in 2000 in the Bay of l'Aiguillon due to floodings resulted in a temporary closure. This resulted in the development of an extensive management plan to restore freshwater quality at the watershed level to sustain appropriate seawater quality in mussel rearing areas.

Product Quality

The Shellfish National Committee decided in 1999 to develop a label to protect the product called "Moules de Bouchots". Specifications include aspects of cultivation (French origin of spat, growth on bouchot, growing area, packaging), product characterization (6 months minimum growth, 20% of flesh) and traceability of the product from spat to market.

In Normandy, a 5-producer organization (OP) also defined specifications for the mussels fished on Barfleur wild natural beds. These specifications concern origin, minimum length (40 mm), product quality (28% of flesh) and sand removal in a specialized treatment plant. Traceability of the product is also certified.[12]

Issues Affecting Future Development of the Mussel Industry

Pests and predators

Mussel culture on longlines has developed rapidly in the open Mediterranean Sea. For the past few years, large sea bream shoals have significantly damaged more than 70% of the mussel stocks cultured on longlines. Predation is rapid and no solution has been found in spite of fishing attempts.

Toxic phytoplankton blooms

Mussels are the most sensitive species to phycotoxins. Sales prohibitions usually occur during the marketing season, leading to significant losses for the local mussel industry. Moreover, inaccurate or dramatized information presented by the media have a negative impact on the brand image of mussels, even in surrounding safe areas. Moreover, several large rearing areas are located near international harbors where deballasting occurs. Introduced species that produce phycotoxins might have an effect on the mussel industry in the future.

Silting up

During the spring of 2001, a large mud deposit that caused mass mortalities was observed in the Somme Bay area, in the north of France. The large amount of mud was linked to high concentrations (500,000 individuals/m^2) of the spionid annelid *Polydora*. No obvious solutions to prevent this phenomenon have been found. Cleaning of the area by farmers, a labor intensive practice, is still the only efficient way to address the problem.

On intertidal flats, mussel culture could increase silting up, leading farmers to leave the concerned area. In Aiguillon bay, a historical site for bouchot culture in France, higher levels of intertidal flats are now abandoned because of silting up.

Space for expansion and potential space conflicts

Spatial expansion of mussel cultivation from intertidal areas to off-shore zones leads to conflicts with traditional users of these zones such as fishermen or tourists (sailing activity). Advantages of off-shore mussel cultivation include improved growth and access to enhanced seawater quality. For fishermen, mussel farmers are considered to be foreigners who are unable to manage their traditional place in the coastal zone. Fishermen also point out a decrease of their fishing rights. However, in the case of overfishing, off-shore longlines can be viewed as a protected area for fish reproduction and survival of the early stages.

Off-shore longlines are often used in zones that are protected from storms. Islands or bays which offer these characteristics are also convenient for sailing activity. Surface decrease of the stretch and landscape deterioration (buoys, rafts, etc.) could be the main conflicts encountered.

New restrictions in terms of pollutant thresholds

New regulations reducing the allowable thresholds of pollutants, mainly based upon the precautionary approach without a scientific basis for public health concerns might over the long term affect the mussel production industry.

Perspectives

The French mussel industry shows a net deficit of production. The main reason is the lack of space for expansion. Current rearing areas are fully exploited and new development requires additional space. However, new development will not significantly improve the supply and demand balance since most of the production in France is seasonal (summer). Urbanization and industrialization is leading to a reduction in water quality, therefore limiting new mussel culture development. Areas dedicated to tourism or protected by environmental regulations are generally not practical for new development, even for extensive aquaculture. Historically in France, shellfish culture has been located on intertidal areas, while fishermen occupy the open sea. That could explain the lack of mussel aquaculture development using the Dutch approach which links fishery and aquaculture methods.

Longlines are the most advanced technology that has developed over the past 10 years. The rearing area (400 long lines, each 100 m long) located in the Pertuis Breton produces between 2000 and 3000 metric tons of mussels each year and numerous spat for several French rearing areas. It offers a good alternative for "bouchot" mussel reared on intertidal flats. However, new surface leases are bound to coastal zone plans integrating other activities and also environmental constraints. There will be conflicts between users are not only for space but also over water quality. In the Pertuis Charentais, conflicts between agriculture and shellfish farming occur over the question of managing freshwater fluxes from the watershed. The estuarine specificities necessary for mussel culture (larval survival, phytoplankton blooms, etc.) could be seen as being damaged by the increased need in agriculture for freshwater for irrigation.

The supply of the French market by both domestic and foreign origins of mussels involves a multi-product market. This segmentation is revealed by the different retail prices for bouchot mussels, *M. galloprovincialis,* and imported products. Recently, this differentiation was increased by certification and the development of trademarks that cover both the origin of the product (Mont St Michel bay, Barfleur) and the cultural practices (bouchot). But these processes need a strong professional commitment to be successful and the individualistic nature of the shellfish sector is now confronted by "hypermarket" strategies characterized by a strong demand for freshness, hygienic quality, traceability, certification and convenience products. One of the keys for the future is which group, the shellfish industry or the organized supermarkets, will drive the product specificities with regard to consumer requirements and needs.

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Mussel Production in Danish Waters

Per Sand Kristensen and Jens Kjerulf Petersen

The blue mussel *(Mytilus edulis)* is an important fisheries resource in Denmark. Currently, all production of mussels is from dredging wild stocks, primarily in the areas of Limfjorden, Kattegat-Belt and the Wadden Sea. Limfjorden is the most important fishing area, with annual landings of up to 100,000 metric tons.

For the last 10 years, total annual landings have varied between 90,000 and 135,000 metric tons, with an value to the fishermen of 7 to 12 million euros. The size of the fishable stock is about 6 to 9 times the annual catch. The efficiency of the fishery varies from 37% to 56%; however in recent years the quota in the Wadden Sea has been fully exploited.

More than 90% of the landings are exported as frozen or canned commodities and Denmark is one of the most important producers of processed mussels in Europe. The value of mussels to the processing factories was Can$67 million in 1999.

The fishery is heavily regulated. There are 51 vessels licensed to fish mussels in Limfjorden, 7 in the Kattegat-Belt area and 5 in the Wadden Sea. The mussel fleet is quite heterogeneous and the areas have different regulations on engine power, overall length of the vessel, and the number of dredges that can be used. The daily and weekly landings are limited, depending on which fishing area the license covers. In the Limfjorden, the maximum allowable vessel size is 8 GRT (gross register tons). Engines are limited to 175 hp. In other areas, there is no size limitation on the vessel, but the maximum allowable engine is 300 hp.

Mussel culture in Denmark is currently occurring on a very small scale or experimental level, although relaying of sub-sized mussels from the fishery in Limfjorden has occurred since 1990. In the period 1994 to 1999, between 5 and 35,000 metric tons of the total catch was discarded per year, of which approximately 40% was undersized (< 46 mm) mussels.

During the last decade, toxic algae have occurred in all fishing areas. But closure of the fishery has been a minor problem. For example, in 2000 the fishery was closed in 5-10% of the areas for 5-10% of the time.

The Danish Shellfish Centre was established in 2001 with the aim of promoting the sustainable use of the shellfish resource and increasing mussel farming in Danish waters. The Center has initiated collaborations with research institutes such as the National Environmental Research Institute and the Danish Institute of Fisheries and Marine Research. Longline production of mussels has been started using techniques similar to those used in Prince Edward Island and Sweden. Experiments with more efficient use of discarded undersized mussels will be initiated. The Danish Shellfish Centre is also involved in other activities, including the production of oyster *(Ostrea edulis)* and lobster *(Homarus gammarus)*.

Type of vessel used to dredge wild mussels in Denmark (Per Dolmer, DIFRES, photo).

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The Irish Mussel Industry

T. O'Carroll

The mussel industry is the largest aquaculture sector in Ireland in terms of tonnage and is second only to salmon in terms of value. The mussel sector is split between bottom cultivation and suspended (rope) culture. In 2001, bottom mussel production was 22,793 tonnes, valued at 12,690,846 and rope mussel production was 7,580 t, valued at 4,205,141. Over 94.5% of the bottom mussels were exported fresh and in bulk to mainland Europe (primarily France). Conversely approximately 80% of rope mussels were processed and exported mainly to Europe (France, United Kingdom, and Italy). The value of processed exports in 2001 was over 21 million. The home market consumption of mussels in 1999 was only 750 t. The main constraint for the bottom mussel sector is the sourcing of seed. In 2001 over 47,000 t of seed were relayed into 11 bays in Ireland (including Northern Ireland) and the industry hopes to relay nearly 90,000 t in 2002. In 2001, over 60% of the seed was sourced from the south Irish Sea. Various methods are used to locate seed, including dredging, RoxAnn and underwater cameras. The rope mussel sector in recent years has had prolonged closures and associated stock losses due to biotoxins. The use of plastic mesh to grow mussels is currently decreasing due to problems associated with the disposal of used mesh. There is still interest in expanding mussel production into more exposed waters and Bord Iascaigh Mhara is looking at various new production techniques both for floatation and ongrowing media.

Introduction

The Irish mussel industry is quite small in European and world terms with total production of rope and bottom mussels in 2001 being 30,373 tonnes with a first-sale value of 16.89 million. In Irish terms this is very significant as it represents half of the total tonnage of Irish aquaculture production and is only beaten by salmon in terms of value. The interesting thing though, in European terms, is that Irish production is continuing to grow and has the potential to double within the next five years (Fig. 1, 2). Like the sea on which it depends, the mussel sector has had, and will continue to have, peaks and troughs in both production and market success.

The details of production, sales, etc., presented here came directly from a detailed survey of the industry carried out by Bord Iascaigh Mhara (BIM) in 2001. A production survey is carried out annually, but last year because of a remedial aid package for the rope mussel sector and requirements for bottom seed mussel management, a more detailed survey was carried out with the full co-operation of the industry. Information on processed mussels came directly from the various companies involved.

This paper relates primarily to the situation in Ireland, but aspects of the bottom culture of mussels in Northern Ireland are discussed.

Terminology and Definitions

Spat = young shellfish, in this case mussels.

Bottom mussels = extensive culture = dredged mussels. In the terms of this paper, bottom mussels are ones that have been relayed onto the seabed from another area. They are therefore termed "cultured" as distinct from wild mussels.

Rope mussels = suspended mussels. Mussels are suspended from floating structures by "ropes" (drop ropes = socks = stockings) or plastic mesh stockings called pergolari.

Longline culture uses floats connected by a rope (head rope) from which the drop ropes are attached. The lines can be attached to a single head rope (barrels attached only at one end and standing upright) or to a double head rope with the floats lying on their sides with rope attached at each end.

1.00 (euro) = Irish £ 0.787564 = Can $1.50.

History

Ireland has a long history of producing and exporting mussels. Indeed an Irish man, Patrick Walton, who was shipwrecked in France in 1235, is reputed to have developed bouchot mussel culture in the Bay of Aiguillon.[2] Starving and desperate for food, he strung nets on poles in an attempt to catch the waders on the soft mud. After a while he noted that the nets and poles were yielding mussels. The poles and nets were modified to also act as a fish trap and over time their use in catching birds was stopped, as mussels became the main crop. Unfortunately the technique did not come back to Ireland at the time.

At the end of the 19th century, Ireland was producing 6,000 to 7,000 t of mussels annually. However, due to overfishing and an outbreak of typhoid fever in England traced back to mussels, production declined. In a 1904 report by Browne[1] on shellfish layings in Ireland (32 counties), 15 commercial mussel beds are mapped out. At the time, approximately 2,000 t of mussels were exported annually to England, Wales and Scotland. They were sent chiefly from Belfast Lough, Castlemaine Harbour, Dundalk Bay, River Boyne, Drogheda and Wexford Harbours. Even at this stage, mussels were not eaten to any large extent in Ireland. In England the mussels were used as food

Figure 1. Bottom Mussel Production 1980 - 2001

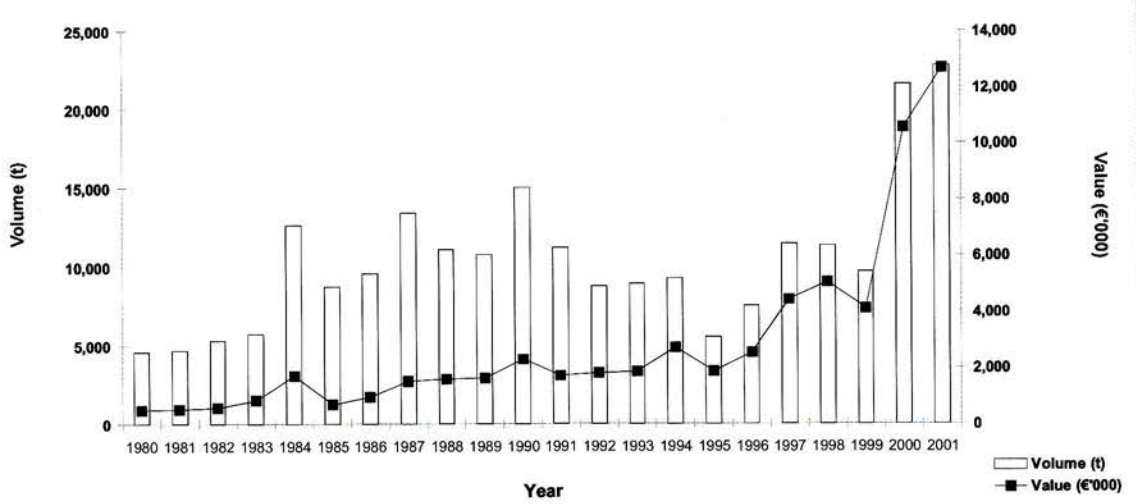
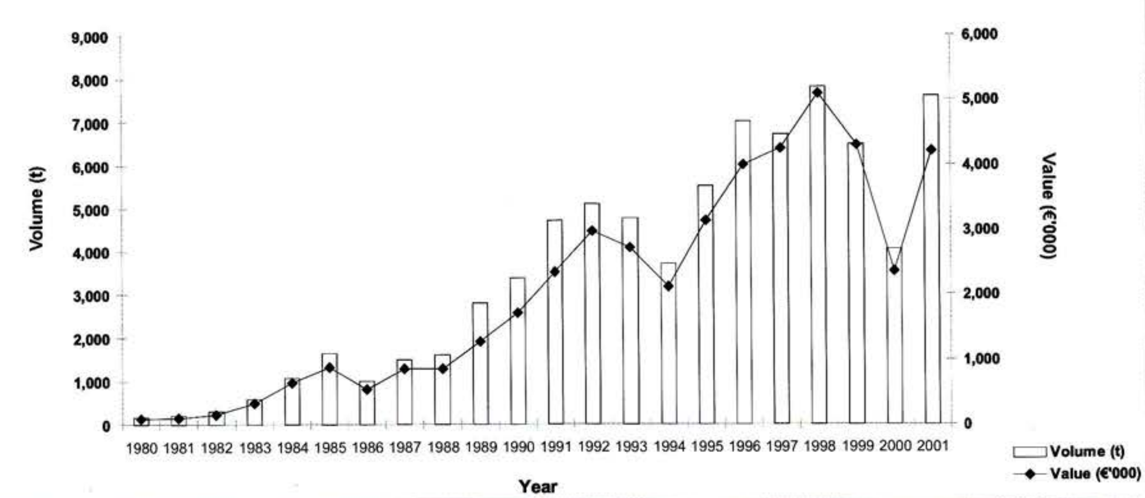


Figure 2. Rope Mussel Production 1980 - 2001



and in Scotland mainly as bait.

Between 1910 and 1939 the annual production of Irish mussels fell to around 1,000 t per annum. In 1939, the English mussel fishery was closed due to World War II. This increased demand of mussels from Ireland and resulted in a quadrupling of Irish production, which came mainly from Cromane (Castlemaine Harbour). A depuration plant was constructed in Cromane at this time (the second one in Europe) and in the following years four factories were involved in processing mussels.

Relaying of beds (i.e., moving seed mussel from intertidal settlement areas to subtidal ongrowing areas) was common practice in Cromane, with beds being relayed between 1950 and 1954. However, spat settlement in the inner bay area of Castlemaine Harbour is sporadic (locals say to expect one good settlement every 10 years) and by 1961 the supply had decreased and the processing factories closed. There was spatfall again in 1963/64 with relaying taking place. In 1965, the first purpose-built dredger was brought into Cromane, but during the 1970s there was poor spat fall.

Prior to the introduction of purpose-built dredgers, dredging was done mainly with small boats. Before the introduction of the outboard in the 1960s, dredging was primarily carried out by a process called "ketching". The dredge was lowered and the boat was rowed with the warp/rope being paid out. Then the anchor was dropped and the dredge was hand-hauled back to the boat. In addition, at very low tides pikes and forks were used to lift the mussels. Small boats with outboard/inboard motors dredging for mussels were common up to 1995 but even on these boats the dredge was hauled by hand. Since then, however, large dredgers have been used in most bays.

Until three years ago, there was one area in Ireland with a small wild mussel fishery of several hundred tonnes a year that was harvested with rakes from a boat. Due to harbour development, the channel was deepened and the mussel bed was removed. As part of the programme, the Harbour Authority tried to re-establish the mussel bed. To this end, approximately 1000 t of seed has been relayed per year for the last two years and there are indications that the bed has been successfully re-established. It will be interesting to see if the fishermen return to using the rake in this fishery, as the water depth has been increased in the channel.

In order to try and overcome the boom and bust in the mussel fishery, the Dutch method of bottom culture (sourcing seed from outside the bay) was tried in an attempt to establish a culture fishery in Ireland. Initial surveys carried out from 1967 indicated that Wexford showed promise. So in 1974, BIM transplanted 800 t of seed which was harvested in 1975 for a value of £85,000. By 1981 there were five purpose-built dredgers operating in Wexford (sourcing seed from the East Coast) which supplied a processing factory employing 120 people.

Apart from Wexford and Cromane, mussel production in the rest of the counties was limited to small

Bottom mussels in Cromane

localised wild fisheries. Since the early 1990s, however, bottom culture techniques have been applied in all areas that have fisheries and in 2001 all mussel production could be termed cultured.

The first Irish trials on "rope" culture of mussels were carried out by Dr. Eric Edwards in 1968 (while he was employed by BIM) in conjunction with the Department of Fisheries. A raft 3 m x 3 m was moored in Castlemaine Harbour, while the Northern Ireland Fisheries Department moored a similar structure in Carlingford Lough.

In the early 1970s, further research in Killary Harbour led to commercial raft-culture trials by Beirteach Teo, a state owned company. In 1977, 10 t of mussels were produced in Killary (the trials in Castlemaine and Carlingford were unsuccessful) and this increased gradually up to 370 t in 1983.

The first longline experiment started in Killary in 1976 and was followed by trials in 1978 and 1979. These initial lines, using New Zealand specifications for headropes and anchors, proved disastrous under Irish conditions. In 1979/80 longline culture (along with rafts), started in Bantry Bay. The use of rafts peaked in 1983/84 and has been on the decline since. Longline production is the preferred method now in use in Ireland. Indeed as part of our work programme for Coordinated Local Aquaculture Management Systems (CLAMS) in Killary Harbour, all the old rafts are being removed from the inner harbour and as part of a national policy, all the blue and green floats are being changed to grey.

Not forgetting the bouchot, trials were carried out by Beirteach Teo in Cromane again from 1972 to 1979 with over 7,000 poles being deployed. A maximum harvest of 60 t was achieved, but the project never reached a fully commercial stage, though crop is still grown on the poles periodically. Until recently, there was another site using the method in County Donegal.

Production Techniques

For bottom cultivation, seed mussels are sometimes sourced from local intertidal areas (Cromane), but they come primarily from subtidal areas. Certain bays, such as Cromane, Carlingford and Lough Foyle, have settlements within the bay which are then relayed onto the ongrowing plots. Most of the other growing areas are dependant on other sources. Traditionally, the Wexford boats sourced their seed from the East Coast of Ireland, though seed does not usually settle in the same location every year, there usually is an annual settlement somewhere that has to be located.

With the development of bottom culture in Lough Swilly, Lough Foyle and Belfast Lough and other areas, the East Coast has become the prime target area for seed. This has caused concern for the Wexford and Waterford mussel farmers as they see their traditional areas being exploited by "outsiders". Ireland and

Unloading bottom mussel seed collected in Arklow

Northern Ireland have a fishing agreement that boats of certain sizes can fish in each other's waters subject to being suitably licensed and registered. This has meant that the bulk of mussels relayed in Belfast and Larne Loughs were sourced either from the East Coast or Lough Foyle. After several meetings with the bottom mussel industry a detailed survey was carried out. The optimum demand for seed for 2002 in the whole of Ireland (North and South) was 89,900 t, of which it was hoped to source 68,000 t from the East Coast. To put this into perspective, 2001 was the best year ever for seed mussel with over 47,000 t being relayed, of which approximately 31,600 t are reputed to have come from the East Coast. In reality the figures for 2002 will most likely be similar to those of the previous year. The above demand is not excessive, as to date in Northern Ireland there are over 1,400 hectares licensed and in the South over 6,000 hectares. In Lough Foyle there is again potential for over 6,000 hectares to be licensed (once licensing regulations are finalised). Being conservative, if all this area is suitable (which some are not), and using a 3-year cultivation cycle (growth varies from 18 months to 30 months depending on the market size required) then over 250,000 t per annum of mussels could be cultured if (and it is a big if) seed could be sourced and if there was the natural productivity to sustain it.

BIM has been carrying out seed mussel surveys around the coast (subject to weather and funding) since the late 1960s, with the surveys being done annually for the last 14 years. A small boat (10 m) fitted with RoxAnn, an underwater camera, dredge and grab is usually used. This year we had hoped to use the new RoxAnn Swath system (7 transducers) but unfortunately it was not ready in time.

At present there are about 35 dredgers operating both in the North and South, with new ones specially designed for Irish conditions planned for the next two years. The loading capacity of the dredgers varies from approximately 40 t to 230 t. There are currently about 50 companies/partnerships operating in the sector with quite complicated intercompany relationships and structures.

When sourcing seed locally, the boats fish a load and steam to the relay areas for offloading. However, if boats other than those from Carlingford and Wexford fish in the Irish Sea, then the seed is offloaded in Arklow or Howth and trucked to the relay areas where it is transferred to another dredger for relaying.

As indicated, the bulk of the rope-cultured mussels are grown using longlines: approximately 75% are grown on the double headrope system, 20% on the single headrope or semi-submerged system, and less than 5% are grown on rafts. The seed originates from two sources, "rock seed" which is collected off rocks and "natural collection" which is collected on coils of collector mesh. All rock seed is packed into socks/stockings/pergolari and when it is half grown it is stripped off, thinned and repacked until it is harvested. From seeding, it takes between 12 to 18 months to get a mature mussel. The natural collection is treated differently in different areas. In some bays the naturally collected seed is stripped off the collectors after 6-9 months and is repacked like rock seed. In other areas, the mussels on the collector are not thinned at all and are grown to maturity on the collectors. There are advantages and disadvantages to both

Semi-submerged mussel lines in Bantry Bay

methods. Rock seed is limited to certain areas, whereas natural spat fall can occur several times during the spring and summer. There are indications that in the southwest of Ireland we have a hybrid mussel with mixed characteristics of *Mytilus edulis* L. and *M. galloprovincialis* Lmk. In the more northern areas, it is *M. edulis* that predominates. This has led to problems of trickle spawning and multiple spawnings, hence the reason processing is favoured for these mussels.

Harvesting is by conveyor and the mussels are usually placed into bulk bags for transport to the processing factories. Individual drop ropes and the continuous system are used. Due to the current difficulty of disposing of pergolari with mussel waste attached in landfills, work is being done to perfect alternative, more environmentally-friendly growing techniques. It currently costs approximately 150/t to dispose of pergolari in the few landfill sites that will take it.

I should mention that currently the aquaculture industry can obtain grants of 40% on new capital expenditure investment under the EU FIFG (Financial Instruments for Fisheries Guidance) programme.

All shellfish production areas are zoned for biotoxins and microbiological classifications. Each production zone has a coding system for tests, e.g., CK-BS-SC stands for Co. Cork, Bantry Bay south, production area South Chapel. Ireland has had considerable problems with biotoxins, with the rope mussel industry being particularly affected. This has led to the complete revision of the classification system which we are constantly trying to improve.

In 1995 and again in 2000, many bays were closed to mussel harvesting for over 10 months (this can be seen in the production statistics in Figure 2) which resulted in crop loss due to storms (slippage and snapping of drop ropes) and also to devalued fouled product. One bay, Bruckless, in Co. Donegal was effectively closed for over 18 months. Closures were mainly due to the detection of diarrhetic shellfish poisoning (DSP) and azaspiracid poisoning (AZP) toxins. We have very little problem with paralytic shellfish poisoning (PSP) and to date amnesic shellfish poisoning (ASP) has mainly affected scallops. Bottom mussel areas are less prone to closures than rope areas, though again in 2000 Cromane was closed which led to subsequent seed losses.

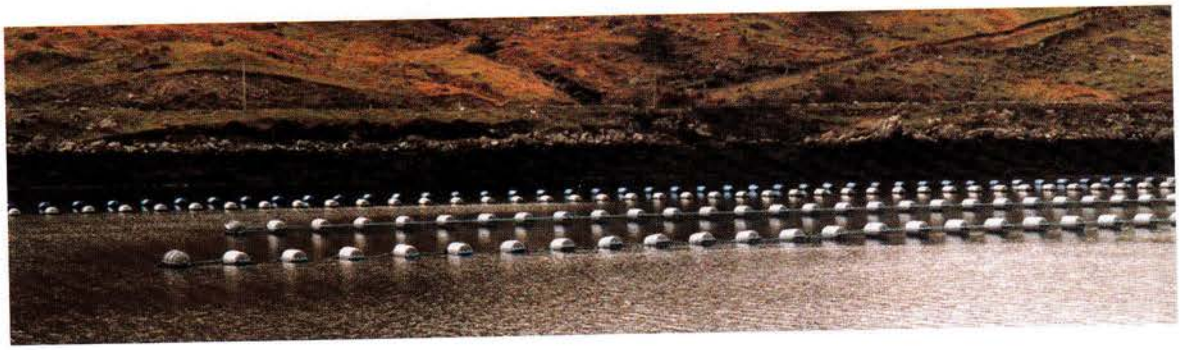
Briefly, all areas are tested for phytoplankton and bioassays and chemical analyses are carried out on the shellfish. In addition, the processors have to test each production batch. The cost to the processors varies from 150 to 300 per batch depending on the tests required.

Production Trends

In 2001 the production of bottom mussels from Ireland (excluding Northern Ireland, but including a proportion of the production from Lough Foyle and Carlingford Lough) was 22,793 t valued at 12,690,846 (average 557/t). Rope production was 7,580 t valued at 4,205,141 (average 555/t). There is a range of selling price for both types of production from 250 to 1,300, depending on size, meat quality and degree of fouling. There was a greater spread of prices for bottom mussels than for rope mussels, which have had a stable price until recently that depended on whether they were sold fresh or to the processors.

If you look at the price per tonne of bottom and rope cultured mussels over the years (Fig. 3), you can see that the price of the bottom product has risen faster in relative terms than the rope product. The main reason for this is the shift away from the processing of bottom mussels in the 1980s and early 1990s to selling on the fresh market. Up until the 1990s, all the Wexford production was processed locally into primarily meat products (frozen or pickled meats with some half shell product). This meant (depending on Cromane's production which goes primarily to fresh sales) that up to 90% of a year's bottom mussel production was processed. However, in 2001 that trend was reversed, with 94.5% of production going to fresh sales.

The regional breakdown of bottom and rope production for 2001 is given in Table 1. As seen, Counties



Longlines in Killary harbour showing the replacement of blue barrels with grey floats

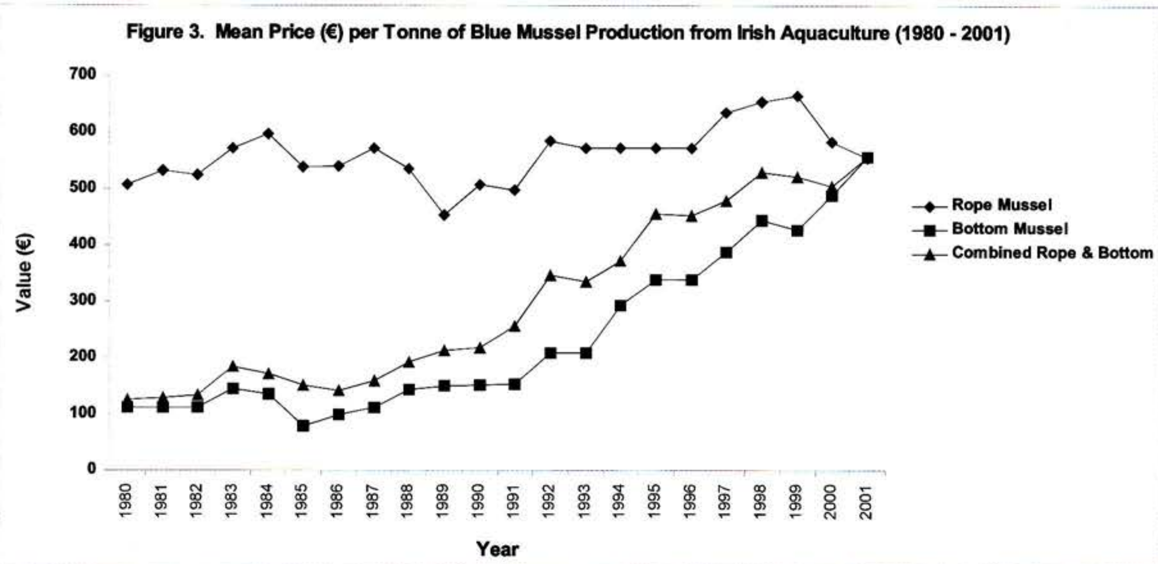


Table 1. The regional breakdown of mussel production in Ireland by sector in 2001.

Year	Production County	Type of Mussel Culture	Volume (t)	Value (euros)	Value (IR£)
2001	Donegal	Bottom	10,472	3,954,526	3,114,443
2001	Kerry	Bottom	1,909	972,251	765,710
2001	Louth	Bottom	1,400	1,653,199	1,302,000
2001	Waterford	Bottom	1,711	1,943,842	1,530,900
2001	Wexford	Bottom	7,301	4,167,027	3,281,801
total			**22,793**	**12,690,846**	**9,994,854**
2001	Clare	Rope	32	20,316	16,000
2001	Cork	Rope	4,886	2,468,852	1,944,379
2001	Donegal	Rope	874	587,015	462,312
2001	Galway	Rope	696	442,321	348,356
2001	Kerry	Rope	644	372,106	293,057
2001	Mayo	Rope	449	314,532	247,714
total			**7,580**	**4,205,141**	**3,311,818**

Donegal and Wexford were the largest producers of bottom mussels, with County Cork leading production in rope mussels.

The employment in primary production in 2001 for the rope mussel sector was 107 full-time, 127 part-time and 287 casual positions, giving a full-time equivalent of 218 people. Similarly for the bottom mussel sector there were 125 full-time, 71 part-time and 88 casual employed giving a full-time equivalent of 175 people.

With the development of rope culture, a processing sector developed mainly because fresh sales can be problematic at certain times of the year (summer time) and it is the general industry view that rope mussels do not travel live as

Table 2. Market distribution of fresh mussels in 2002 (by percentage volume).

	France	Holland	Spain	UK	Other
Percentage	63	9	13	3	12

Table 3. Market distribution of processed mussels in 2002 (by percentage volume).

	France	UK	Italy	USA	Other
Percentage	38	26	13	13	10

well as bottom cultured mussels. As a result, 80% of the rope production was processed in 2001. This percentage would have been higher except quite a lot of product was fouled due to prolonged closures in 2000 due to biotoxins. In 2002 the average price of mussels to processors has increased to 760/t and this price is set to be maintained because of high market demand. In 2001 and 2002, processors imported fresh mussels from Spain, Greece and other countries because they had exhausted supplies in Ireland.

Table 2 shows the market distribution for fresh mussels in 2001. France was by far the largest importer of Irish mussels, with 63% of the tonnage being sold there. Well over 90% of fresh sales are sold in bulk format in either 1-tonne or 25-kg bags.

In 2001 a total of 7,350 t of mussels were processed in Ireland by five companies, Bantry Bay Seafoods Ltd., Fastnet Mussels Ltd., Carrokeel Seafoods Ltd., Connemara Seafoods Frozen Ltd. and Atlanfish Ltd. with sales valued at over 21 million. Table 3 shows the market distribution of processed mussels in 2001 with France being the main importer with 38% of the market share, but followed closely by the UK with 26%. The customer breakdown for processed product (Table 4) indicates that catering and retail are fairly even with 43% and 39.3% of sales respectively with manufacturing making up the remainder. By far the largest form of processed product is the frozen "vac pack" with 74% of the sales being in this form (Table 5). The chilled "vac pack" product accounts for 13.5% of the sales volume with IQF (in shell) coming in at 7.5%. The processed products are

Processed mussel product

sold under the brand names of Bantry Bay Mussels, Moule de Connemara, Carrokeel, Murphy's Seafood, Molly Malone, etc.

Most processors feel they can expand production and sales, but at present the limiting factor is the high competition for supply of raw material. This in turn has renewed interest in expanding mussel production into new areas, most of which are quite exposed.

Consumption of mussels, whether fresh or in a processed form, is still low in Ireland. A home market survey in 1999 estimated that the total consumption of mussels in Ireland was only 750 t and this included imported product from New Zealand and Denmark.

Industry Issues and the Future

The main problems for the industry are linked closely to its future development. One of the prime concerns are biotoxins and the associated closures and ever-increasing food safety implications. The industry requires the development of a quick, cheap broad-range screening test for biotoxins.

For the bottom mussel sector, the consistent supply of good-quality seed mussels along with improved returns on seeding to harvest are required. The seed supply can be improved with a better understanding of the dynamics of settlement along with improved survey techniques. Due to the increasing value of the product, the option of using hatchery-produced seed may become economically viable in the future.

The regulation and management of seed mussel stocks needs to be improved and it is hoped to address this within the next year.

Rope mussel production needs to be expanded by improving returns at existing sites and by developing more exposed locations.

Generally for both sectors the returns per hectare, reduction of wastes, improvement of seed return ratio and improved quality can be achieved. BIM is working closely with the industry on all these areas and is specifically developing a Quality Mussel Scheme to EN 45011 standards.

As in the past, the best hope for the successful future development of the mussel industry is in the people involved in the industry.

I would like to thank the mussel processing industry for supplying market information. In addition I would like to thank the members of the Aquaculture Technical Section, BIM, for providing various data inputs for the paper and presentation.

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Table 4. Customer breakdown for processed mussels in 2002 (by percentage volume).

	Catering	Retail	Manufacturing
Percentage	43.0	39.3	17.7

Table 5. Product range of processed mussels in 2001 (by percentage volume).

	Vac Pack/ Sous Vide Frozen	Vac Pack Chilled	Individually Quick Frozen (IQF) (in shell)	Other (meats, half shell, etc.)
Percentage	74.0	13.5	7.5	5.0

Overview of the Mussel Industry in Chile

Juan E. Illanes

Although mussel farming began in Chile in the late 1960s, it was not until the 1990s that large volumes of mussels were shipped to international markets. Exports grew approximately 200% in 2001, compared to the previous year. The trend in the world market for mussels has been toward increased farmed production, which now accounts for 70% of production. Almost all (98%) of the production is the Chilean mussel, *Mytilus chilensis*. The remainder consists of the ribbed mussel, *Aulacomya ater*, and the shoe mussel, *Choromytilus chorus*. Although the Chilean production of about 30,000 metric tons of raw material is insignificant compared to countries like China, since the late 1990s the mussel farming industry has become one of the most promising aquaculture activities in Chile.

History of the Mussel Industry in Chile

The rearing of molluscs in Chile started with the Chilean oyster *(Ostrea chilensis)*, a species that has attracted the attention and interest of local authorities since the end of the 19th century. In 1907 a law established a fishing ban on oysters and mussels to prevent over-fishing. A state-owned oyster farm created in 1930 near Ancud marked the beginning of marine aquaculture in Chile. Later, in 1943, a law was passed to protect both mussel and oyster species. Also in 1943, the first mussel farm was created in Quellón on the southern tip of Chiloé island.

Seventeen long years went by, and no important events took place in Chilean aquaculture until the extremely traumatic earthquake of 1960 in the south of Chile. The earthquake had disastrous economic and social consequences in a vast part of the region. It profoundly modified the substrate in the coastal and intertidal zones and destroyed the primary natural mollusc beds. In 1961, the government's response to the disaster was to start the first systematic experiments in mollusc farming. The Putemún mussel farm was created near the town of Castro. On the basis of the initial experiments at Putemún, farming of bivalve molluscs such as oysters, shoe mussel *(Choromytilus chorus)*, Chilean mussel *(Mytilus chilensis)* and ribbed mussel *(Aulacomya ater)* was encouraged, mainly in the south of Chile.

The 1960s were characterized by a marked increase in the number of state-owned oyster and mussel farms in the X and XI regions, which had been severely affected by the earthquake. There were also sporadic private attempts at mollusc farming. The mussel farms used Spanish and French technology, with special interest in suspended culture using rafts and longlines. Unfortunately, the use of these technologies was not complemented by biological studies of the species being grown and their culture requirements. This shortcoming in the development of the industry was a decisive factor in the slow progress of the mussel culture sector, as it was later proved that only semi-intensive farms were feasible for growing and fattening wild seed.

To promote commercial production, the state-owned facilities for mussel culture were transferred to private companies in the 1970s. But it was only in the 1980s and the early 1990s that the development of private mollusc enterprises became important and the economic activity associated with scallop culture was the most significant.

Culture versus Wild Mussel Activities

The first attempts at mussel farming in Chile were carried out in the late 1960s but it was only in the 1990s when we witnessed the shipment of significant volumes of mussels to international markets. Exports grew approximately 200% in 2001 compared with the previous year. The trend in the world market for mussels, including the mytilids and the ribbed mussel, *A. ater*, has been towards increased farmed production, which now accounts for 79% of world production. In Chile, mussel production is chiefly made up of the Chilean mussel *(M. chilensis)*, which represents 98% of farmed mussel production. The remaining produc-

Table 1. Characteristics of cultured and wild Chilean mussels

Characteristic	Mussels from Natural Beds	Cultured Mussels
Growth	Slow: 3.7 mm in 20 months	Fast: 7.7 cm in 20 months
Valve thickness	Thick	Thin
Fouling	Heavy	Light
Cleanliness	Interior contains sand and gravel	Completely clean
Meat yield	7 to 10%	18 to 26%
Production	Seasonal, depends on regulations	Continuous
Size and aspect of meat	Small and heterogeneous	Large and uniform, with an attractive aspect

tion comes mainly from the wild fishery, some cultured production of the ribbed mussel *(A. ater)* and, to a lesser extent, the shoe mussel *C. chorus*.

The mussel farming industry has grown significantly in recent years and is currently one of the most promising activities in Chilean aquaculture. Collection of wild mussels is now mostly recreational, or is done on a subsistence basis by a few artesanal fishermen, but it does generate significant economic returns.

With the information now available on aquaculture technology and the biology and eco-physiology of mussels, it is clear why cultivated Chilean mussels are of better quality, have a greater meat yield and grow more rapidly than wild mussels. Table 1 shows the characteristics of cultured mussels compared with those of wild Chilean mussels

Growing and Processing Technology

In Chile, mussels are naturally distributed from the IX to the XII Regions and occur primarily in areas of low salinity, especially where freshwater mixes with seawater. Because of geographic factors and water quality, mussel culture activities are concentrated in the X Region, specifically in two

Harvesting mussels by hand

Attaching mussel seed to the growing cords

areas: the Island of Chiloé, which produces about about 20,000 metric tons of raw material, and Calbuco, which produces 10,000 tons of raw material.

Mussels reach sexual maturity in the spring and summer, at about one year of age, as long as environmental conditions are favorable and there is an adequate supply of food. The larval period lasts 25 to 30 days and, once the post-larvae set, 2 to 3 years are required for the mussels to reach commercial size (grow-out time varies with environmental conditions). Mussels tolerate a wide range of salinities (4 to 32‰) and temperatures (3° to 28°C).

The most widely used approach to culturing mussels in Chile is suspended culture based on Spanish and French technology. Suspended systems use rafts and longlines, of which the latter are the most popular. Rafts are composed of a flotation system (floats) and a wooden gridwork from which the culture lines are hung. There is an anchoring system to moor the raft.

The production capacity of a raft depends on its dimensions, local environmental conditions, and management of the culture operation. An 8 x 10 m raft has a usable surface of 75 m^2 and is able to support 321 lines that are 8 m in length. If each line yields about 40 kg of mussels, the production of the raft will be about 13 metric tons per year.

Longlines are made of polypropylene, polyethylene or nylon rope and are 12 to 16 mm in diameter and 100 to 200 m in length ("mother line"). The lines are suspended horizontally in the water column by means of a series of floats. There is a mooring or anchor at each end of the mother line securing it to the sea bottom. The mussels are suspended on cords along the mother line at 50-cm intervals. A 100-m longline, with a 40-kg yield per cord can produce 8 tons of mussels per year under normal environmental conditions. At present, double longlines are also being used, with the two parallel mother lines being separated by floats.

Figure 1. **FRENCH MODIFIED SYSTEM**

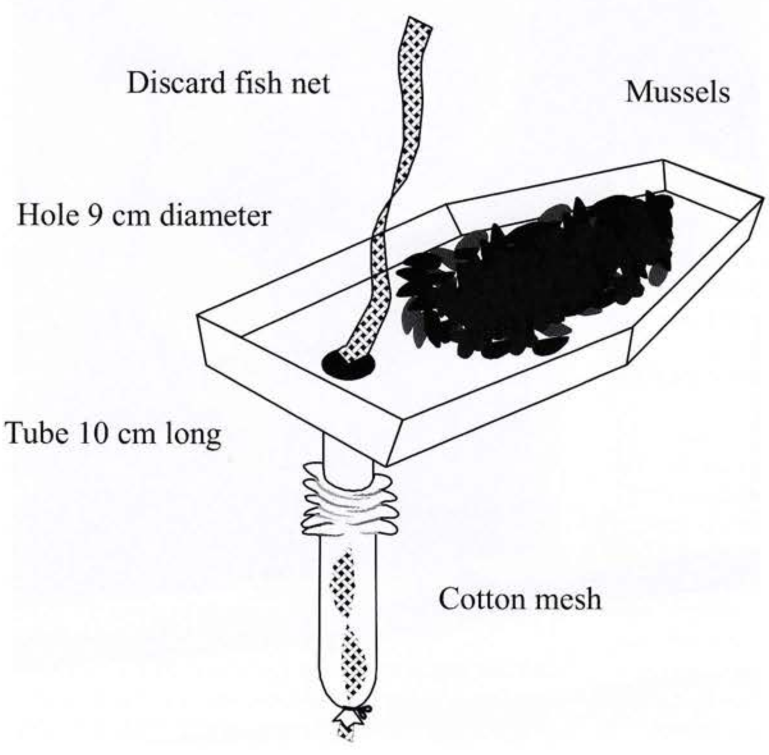


Table 2. Evolution of the value of Chilean mussels.

Year	Meat Value per Kilogram (US$)
1997	2.70
1998	2.60
1999	2.30
2000	2.05
2001	1.90

Seed can be obtained from natural sets or can be artificially produced in hatcheries. Capture of natural seed is relatively economical, but its availability is irregular. Natural seed is obtained in the environment using collectors suspended from longlines or rafts, and its capture and removal requires authorization from the Subsecretary of Fisheries. Hatchery production of seed is not presently used, but if an efficient system could be developed, there would be no seasonal limitation on seed availability.

The collectors most commonly used consist of lengths of discarded fishing net, which provide a suitable surface for mussel settlement. The net pieces

Table 3. Comparison of rafts and longlines for culturing mussels.

Raft Culture	Longline culture
Useful in areas that are protected from the wind and swell	Greater flexibility in placement of culture system. More adapted to conditions at sea, and may be installed in more expsoed locations
Mussels in the center of the raft system may experience slower growth	Growth of muusels is more homogeneous
Cords must be rotated	Rotation of cords is not required.
Mussels subjected to less stress	Mussels subjected to higher stress, which may affect growth of the mussels

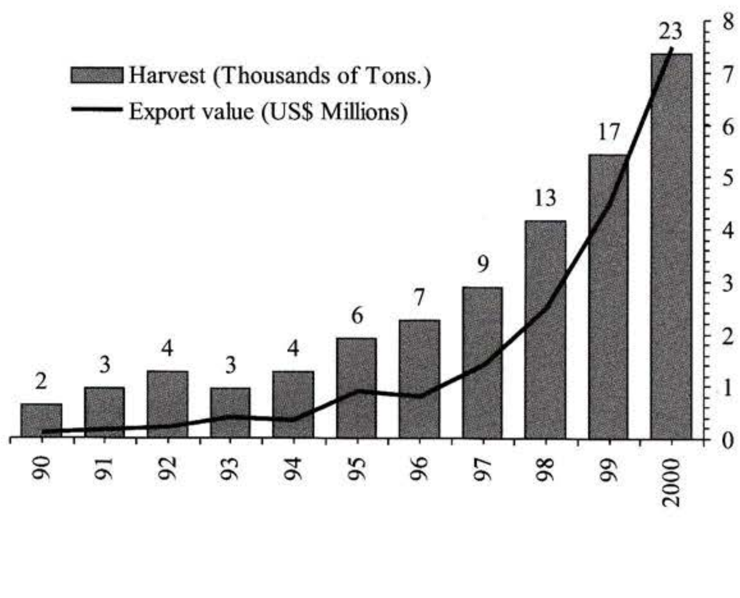


Figure 2. Harvest and Export Value of Chilean Mussels 1990 to 2000

Table 4. Raw material (metric tons) by resource and production line 1992-1996

Resource	Year	Raw material by production line					
		Cooked	Fresh refrigerated	Frozen	Smoked	Canned	Total
Chilean mussel	1992		185	1768		7823	9776
	1993		310	2807	5	6339	9461
	1994	5	15	2821		6478	9319
	1995	84	148	3700		6356	10,288
	1996	1146	338	3121		6080	10,685
	1997	1907	910	3740		5853	12,410
	1998	2111	1159	6413		5749	15,432
	1999	576	608	12,076		5768	19,028
Ribbed mussel	1992		275	162		5916	6353
	1993		642	489		5227	6358
	1994	4	76	286		6846	7212
	1995	31	134	399	7	4794	5376
	1996	90	306	619		4550	5565
	1997	113	93	382		4445	5033
	1998	71	93	499		5039	5702
	1999	37	526	580		2884	4027
Shoe mussel	1992					2	6
	1993					10	10
	1994						
	1995	8		2		28	38
	1996	5		2			7
	1997	4					4
	1998	1		3		42	46
	1999	2		10		3	15

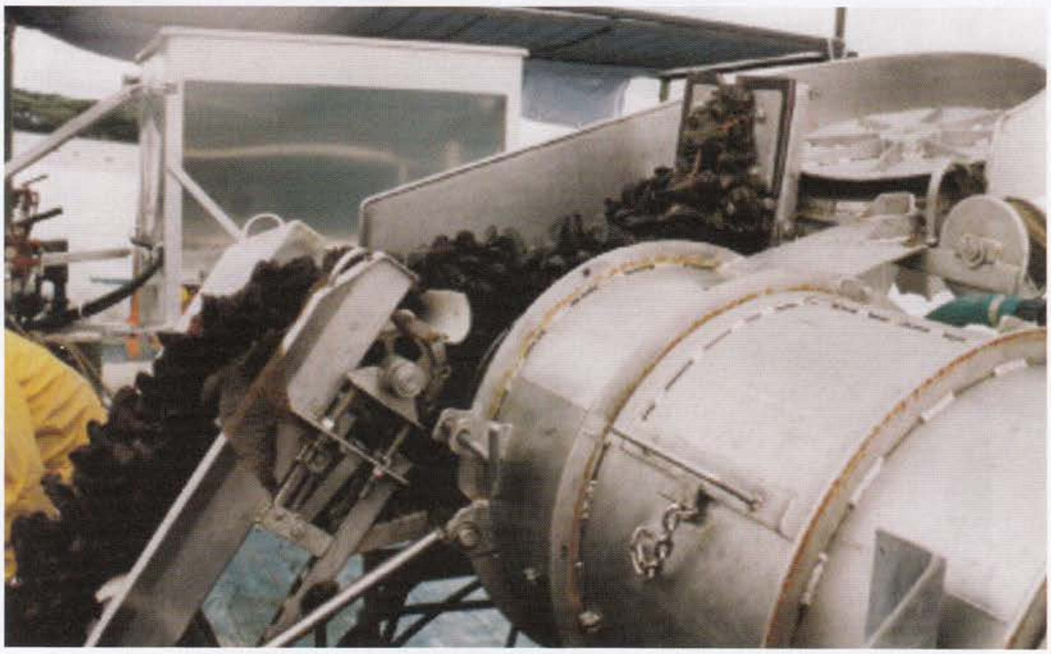
measure about 20 to 25 cm in width and 8 meters in length. A stone is tied into the lower end of the collector as ballast, so that it is maintained in a vertical position.

Collectors are suspended from rafts or longlines, separated by 15 to 20 cm. Seed capture and placement of collectors is carried out at one of three authorized centres. Users pay a fixed price per collector or cord. If the collector captures between 0 and 3500 seed, the price is US$0.30 per collector; if the collector captures more than 3500 seed, the price is US$0.70 per collector.

Installation of collectors normally begins in the early spring in the X Region and they remain in the

Table 5. Total exports (metric tons) of mussels based on country of destination 1995-2000

Country	Year					
	2000	1999	1998	1997	1996	1995
Portugal	914	90	0	0	0	0
Argentina	846	830	618	473	337	393.6
Italy	767	168	0	0	0	0
Spain	472	943	221	0	1	1
USA	435	44	8	0.5	34.5	2.3
Uruguay	125	118	80	31.3	30.9	27.2
South Africa	85	0	21	0	0	0
Australia	37	0.1	0.14	0.2	9.8	0
France	36	0	72	0	0	0
Colombia	22	6	7	8.6	8.8	4.8
Brazil	1	13.4	57	47.2	73.2	36.8
Total Exports to the 11 Major Importing Countries	3740.0	2212.5	1084.1	581.9	514.1	490.0
Total Exports	3908.4	2251.0	1169.0	717.4	539.9	518.58
Number of Countries Importing Chilean Mussels	30	24	20	20	17	21



Mechanized harvest — Pulling the mussel cords out of the water and detaching the mussels from the cord

water for 4 to 6 months, during which time the seed reaches a length of 2 to 3 cm. The collectors are then removed from the water and are taken to the culture centres. In favourable settlement periods, collectors obtain an average of 4000 seed.

There are three systems being used to attach the seed to the longlines: the Spanish system, the French system, and the modified French system. In the Spanish system, the growth cord is a polypropylene line, around which the seed are wound in a rayon mesh. After 10 to 15 days, the mesh dissolves in the water, which is a period sufficient for the mussels to secrete byssal threads and adhere to the growth cord. To avoid slippage of the mussel mass down the cord due to the progressive increase in the weight of the mussels as time passes, wooden skewers 20 cm in length are inserted through the growth cord at 40-cm intervals.

The French system uses a cotton sleeve and tubular nylon mesh, both 6 to 8 m in length. Using a funnel, the mussels are placed into the cotton sleeve; the nylon mesh is on the outside of the cotton sleeve. Once the cotton sleeve decomposes in the sea, the mussels slowly pass through the openings of the nylon mesh, which remains at the centre of the mass and acts as the growth/support cord.

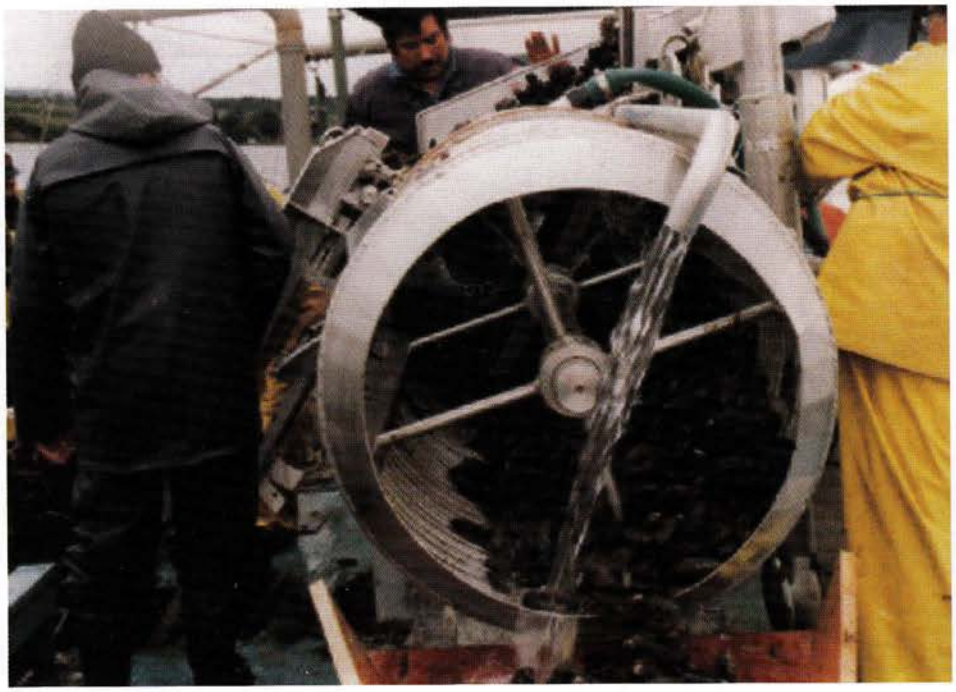
The modified French system is presently the one most commonly used in Chile. It is similar to the preceding system, but the central cord is made of discarded fishing net placed within the cotton sleeve. Preparation of the central cord involves using a straight funnel (9 cm in diameter and 10 cm long). A 10-cm length of cotton sleeve is cut and rolled back over the extreme lower part of the tube. The fish net, 25 cm in width and 10 m in length, is at its end. Experience has shown that a cord 6 m in length can hold 3,000 seed of about 2 cm average length. When higher seed densities are used, there is a greater degree of seed loss because of dislodging. Figure 1 shows the modified French system.

Once the seed is placed into the cords, the growth cords are installed on the rafts or longlines until the mussels reach a commercial size of 6 to 7 cm in length, which is normally obtained in 12 to 18 months, depending on local conditions.

Product Forms and Markets

In 2000, Chilean mussel harvests accounted for 53% of the total aquaculture production in Chile. Production and exports in 2000 both exceeded 1999 figures by far: 45% and 30% respectively. However the price dropped considerably in the destination markets because of an increase in both Chilean production and the world supply of mussels.

The most important destination market for Chilean molluscs is Europe, followed by America in a much lower proportion. In recent years, producers have started to explore market possibilities in Asia. The Chilean mussel *(M. chilensis)* continues to be the most popular product worldwide; the ribbed mussel



Mussels coming out of the mechanized harvester, scattered, washed and cleaned

(A. ater) is sold to some countries but it has been difficult to introduce this species to other countries.

Among the strategies used for introducing these mussel species to markets are the development of value-added products and improving processing quality by incorporating new technologies, such as automated lines to shell the products and automated sizing machines.

In recent years, Chilean mussel exports have had sustained growth, reaching a volume of 3908 tonnes in 2000 and producing a dollar income to the country of about US$8.3 million. By volume, 94% of exports are frozen product, 5.9% are canned, and 0.1% are sold fresh refrigerated. It is important to note that 99% of the exports are Chilean mussels and the rest are ribbed or shoe mussels.

In 2000, Chile exported mussels in various forms to 30 countries, with the most important being Portugal with 914 mt (24%), Republic of Argentina with 846 mt (22%), Italy with 767 mt (20%), Spain with 472 mt (12%), and the USA with 435 mt (11%) (Table 5). From an historical point of view, exports at the end of the 1980s showed an increase to the European market, principally Spain. However, beginning in the 1990s, the Latin American market began to consolidate, particularly Argentina, which increased its demand for frozen mussels from 132 mt in 1992 to 792 mt in 2000.

Issues that will Affect the Future Development of the Industry

Due to geographical conditions and water quality, Chile's mussel culture activity is concentrated in the X Region, specifically in two areas that include the island of Chiloé which has two-thirds of the total production (about 20,000 mt of raw material) and Calbuco, where the remaining third of the raw material is produced (10,000 mt).

In contrast to aquaculture activities such as salmon culture, mussel culture is a highly dispersed activity. The following is a list of the characteristics of the industry that may affect its future development:

- There is a lack of complete vertical integration. Seed collectors, grow-out specialists, processing plants, and sales enterprises function separately. Only a few companies, such as Pesquera Pacific Farmers and Granja Marina Chauquear, both produce and commercialize their products.
- There is a threat to the cultivation sector from the processing companies, which are trying to integrate vertically.
- Very few producers are able to offer more than 2,000 tonnes of raw material; most of the production is dispersed among small businesses which culture on a small scale. This situation, added to the fact that a large number of growers are located far away from cities, may explain why the mussel culturists have an unusual system of labour organization.
- Only 50% of the mussel culture activity in Chile is represented by labour organizations, with the remaining half unrepresented. Persons engaged in mussel culture who are represented by labour organizations belong to one of the four following entities: Association of Mollusc Cultivators of Calbuco, Association of Mussel Cultivators of Chiloé, Association of Mollusc Cultivators of the Municipality of Dalcahue, and Labour Association of Aquaculturists and Sea Workers of Yaldad Sound.
- There is a lack of mechanization in the the production process. All activities are carried out manually, and although this reduces costs at present, it is clear that in the long term the companies that fail to modernize will have a reduced capacity to compete in markets that are increasingly exacting.
- There is uncertainty in seed supply, which at present is based entirely on wild capture.
- There are difficulties in obtaining credit and there is an absence of financial sources for the development of new technologies and for operating capital.
- There are problems of certification of waters for shellfish culture. Blooms of toxic algae (red tides) have been increasing in recent decades because of a lack of vision in the management and control of this scourge. Codes of practice and a permanent sampling program need to be established to control this problem in a systematic and efficient way (e.g., the effects of waste production by salmon culture).
- Exploration of new markets and the incorporation of value-added processes which make the products more attractive and profitable are required.

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The New Zealand Greenshell™ Mussel Industry

Bruce Hearn

The New Zealand Greenshell™ mussel industry has developed from very small beginnings in the 1970s to a 75,000 tonne industry today. It is based solely on the indigenous Greenshell™ mussel *Perna canaliculus.* The industry is highly mechanized in both growing and processing technology. The principal form in which the product is sold is frozen in the half shell. New product forms are being investigated, as is the potential for development of nutraceuticals, and organic certification. The Greenshell™ mussel is considered by many to have anti-inflammatory properties and the early industry was based on this potential. Growers turned to developing food markets because the extensive clinical trials required by US regulators were prohibitively expensive. Production of Greenshell™ mussels exceeded demand for many years. Extensive monitoring of growing waters for faecal contamination and biotoxins is largely industry led and funded. Total carrying capacity of growing waters is receiving increased attention. An environmental management system has been implemented and adopted by the industry along with an "adopt-a-beach" programmes.

Introduction

The New Zealand Greenshell™ mussel industry has developed from very small beginnings in the 1970s to a 75,000 tonne industry today. It is based solely on the Greenshell™ mussel *Perna canaliculus* which is indigenous to New Zealand.

New Zealand is located in the South Pacific. It has a population close to 4 million and is about the same size as the United Kingdom. It has 60 million sheep, the America's Cup, a passion for rugby rivalled only by the Canadian passion for ice hockey and undoubtedly the best mussel in the world (there were 8 New Zealanders at the First International Mussel Forum to confirm that status!).

New Zealand is a huge distance from the major markets in North America, Asia and Europe. As a consequence we have had to rely on frozen product which generally is less lucrative than fresh. We have needed to become efficient and mechanised in growing, harvesting and processing technologies but fortunately we have a species that has relatively few problems. We have a cheap and reliable spat source, few fouling organisms, excellent byssus attachment, good growing conditions and low pollution. We also save our ice for our gin!

Mussel farm in Marlborough Sounds, New Zealand

Mussel farms are located in Marlborough, Coromandel and Stewart Island. Currently there are about 600 mussel farms nationally totalling 4755 hectares with about 580 of those, or 2450 hectares, in Marlborough Sounds. Most farms are located within 200 meters of the shoreline in a "ribbon type" development.

The commercial species is *Perna canaliculus* which grows up to a size of 200 mm and is one of the larger cultivated mussels. Worldwide trademarks protect the name Greenshell™.

Mussels are harvested at a size of 90 to 100 mm shell length and around 85% of production is processed for the export market and sold in over 60 countries. The main export form is frozen on the half shell and that makes up about 90% of production with the balance being in frozen mussel meat, frozen whole shell, marinated, smoked, powdered, and some chilled and fresh product.

The industry is comprised of a mixture of private owner operators (both large and small), many of whom have share farms or contracting arrangements with larger companies that own their own farms and harvesters and are vertically integrated to various extents.

We also grow the blue mussel *Mytilus galloprovincialis*—but not intentionally. This mussel is our major pest as oversettlement on our rope culture farms. You call this "second set" in Canada, but we can have several sets.

Farms are generally about 3 to 4 hectares (7.5 to 10 acres) in size, produce up to 150 tonnes of mussels per year and hold up to twelve 110-m longlines. The water depth ranges from 8 to 40 m. Water temperature ranges from 8°C in winter to 22°C in summer, but can go to 26°C in some sheltered, shallow bays.

The processing sector of the industry consists of a number of large and small factories with capacity ranging from 60 to 550 tonnes per week.

Growth of the Industry

The industry has grown from very small beginnings in the early 1960s and 1970s into a significant contributor to the economies of smaller communities of New Zealand. Production in 1977 was about 600 tonnes: 400 tonnes in Marlborough and about 200 tonnes at Coromandel in the north. Production in 2001 was 64,000 tonnes. This was considerably down from previous years due to drought conditions affecting the nutrient supply in some areas.

Financially the industry has struggled for most of its development years, due to production exceeding the established markets at the time. Prices were forced down and this was accentuated by adverse exchange rates at times. Currently it is in good heart but it could easily be reversed by the strengthening of the New Zealand dollar against the US dollar and oversupply problems.

In the early 1950s and 1960s there existed a small dredge fishery for large greenshell mussels of a size around 150 mm. Surprisingly it was this small fishery that provided the impetus for the establishment of the culture industry we have today.

Clearing of the bush for pastoral production produced substantial debris on which the original mussel

Mussel farm in Marlborough Sounds, New Zealand

beds were built up. Crude dredging left glutinous mud, little attachment surface for larvae, and doomed the small dredge industry. Surveys of wild catches in the north from 1961 to 1966 illustrate the point (expressed as mean catch per 2 minute tow):

- June 1961: 92.3 lbs (42.0 kg),
- June 1962: 20.3 lbs (9.2 kg),
- May 1963: 8.8 lbs (4.0 kg),
- 1964: no survey was done,
- July 1965: 0.6 lbs (0.3 kg),
- July 1966: 0.5 lbs (0.2 kg).

In 1965 one of the fishermen constructed a small pontoon 9 ft x 9 ft (2.7 m x 2.7 m) which he moored in a sheltered bay. Beneath the pontoon he suspended 230 bundles of titree brush (a native brushwood). A good spat take with an average of 180 mussels per 18 inch brush resulted. After estimating the market value of the mussel spat he decided his troubles were over and his fortune made. Six years later he was no further ahead, but so began the New Zealand Greenshell™ mussel industry!

In 1968 work was commenced in the Marlborough Sounds, modelled on the Spanish cultivation system of rafts and the hand binding of mussels onto ropes, and a number of rafts were constructed. Many of the rafts broke up and sank —some more than once.

In 1974 a New Zealand scientist (North American by origin) visited Japan and came back with bright ideas of how the longline culture system used for Pacific oysters could be adapted for mussels. Japanese floats smuggled to New Zealand in a Japanese squid boat formed a trial line and I placed the first commercial longline in the Marlborough Sounds in 1974—12 mm backbones, 18 mm warps and, at best, 30 kg steel anchors in an area with reasonably strong currents. With our current knowledge, the result was fairly predictable!

Growing Techniques

The main growing area, the Marlborough Sounds, is composed of drowned river valleys and closely resembles the rias of Galicia in Spain, a region well known for its established mussel cultivation industry.

Over time, rafts, rope culture, and Spanish lace for binding mussels to ropes gave way to new developments utilising longline culture.

Anchoring for the longlines usually uses up to 10-tonne concrete blocks (8 tonnes being a common size) or screw anchors which I developed as an idea from my previous employment 24 years ago. The screw anchors have a helix of 600 mm and shafts up to 50 mm in diameter. They are wound 6 m into the sea floor. In low tidal areas screw anchors are favoured because the sharper warp angles achieved allow more of the farm area to be utilised for production. Concrete

Concrete anchor blocks

anchors and screw anchors are accurately placed by using differential GPS which is on board several contracting vessels.

The industry now is exclusively longline culture with double backbones 90-300 meters in length (although commonly 110-160 meters in length) and usually 24-32 mm in diameter with warps ranging from 24-36 mm depending upon prevailing conditions. Floatation is provided by rotationally moulded black polyethylene floats of a capacity of approximately 300 liters which support one tonne of wet weight mussels when harvested.

Eighty-five per cent of spat comes from 90 mile beach (Kaitaia spat) at the top of the North Island, with the rest being caught locally.

Mussel spat on seaweed

In certain weather conditions on 90 mile beach, large quantities of fine red seaweed are deposited on the open surf beach. Mussels, varying in size from 500 microns to 5 millimeters, attach to the seaweed in the order of 1 million to a kilogram. The spat are collected and shipped to the mussel growing areas by the tonne. As an independent grower I usually take 300-400 kg of spat at a time, but the large corporate growers will take up to 5 tonnes at once. This quite regular source of spat has been one of the corner stones of our industry.

This seaweed is placed on continuous rope which has a lead core—we just call it "lead rope". The lead core is encased in a plastic tube. The seaweed is surrounded with cotton or a cotton/polycotton mix and

Suspended culture mussel farming

applied at the rate of between 20-40 meters per kilogram. Spat survival rates are between 0-20%. Some failures occur, but more usually these spat ropes hung at 5 to 12 meter drops require stripping and re-seeding (intermediate seeding) because there are too many spat on a rope and if left they fall off or grow unevenly. Wastage is sometimes high because the spat is relatively cheap. Some of the larger vessels and operators grade spat before final seeding if intermediate seeding has not taken place.

During June 2000 an industry closure for transfer of seaweed was put in place because of the presence of the toxic dinoflagellate *Gymnodinium catenatum* in the area the seaweed was being collected. This bloom came to parts of our mussel growing area, but did not impact the main growing area. A industry-managed voluntary code of practice was put in place to control the transfer of spat even after the bloom had dissipated because large numbers of resting cysts remained in the seaweed. To deal with the problem, some spat was treated in foam fractionation plants and other techniques were employed for getting the spat to walk off the seaweed and onto ropes, leaving the cysts behind. The closure was finally lifted in August 2002.

Losses of mussel spat occur from fish predation and competing fouling organisms such as *Ciona intestinalis*, a sea squirt that appears episodically. Less often there is a problem with other fouling organisms, but if they appear in quantity, they cause the spat to leave the rope and live on the fouling organism. When the fouling organism disappears or completes its life cycle, the mussel spat disappears with them.

Some 15% of spat requirements are obtained by the more traditional method of hanging catching ropes in appropriate areas.

Quite extensive larval and spatfall monitoring programmes have been in place for many years to assist with the efforts and these have proven very useful. There are three types of Greenshell™ mussel spat originating from different geographic areas. Each of the types have different and complementary condition cycles and this provides the industry with almost year-round production. It is interesting that spat from Kaitaia performs quite differently from locally-caught spat and those caught in other areas of the South Island.

The spat from the various sources can often be identified by their slightly different shell colouration, although their general morphological characteristics are similar.

It is clear by observation that some hybridization of the different types of Greenshell™ mussels has occurred in the growing areas, although it only seems to cause a problem with the resulting crop and differing condition cycles when ropes laid for spat catching are left in the water for extended periods. Although no studies have been done, we believe that the different spawning patterns allow spat catching of each individual type of spat when they are farmed in the same area because they spawn at different times. Different growth rates are also observed and these are sometimes significant depending upon the area involved. While traditional methods of spat collection are considerably more expensive, they are undertaken mainly to give continuity to harvesting and processing.

Mussels are stripped, de-clumped, washed and finally mechanically reseeded at densities of 140 to 180 per meter by encasing the spat in a cotton tube which rots leaving the mussels attached to a 14 mm soft lay hairy rope. I saw a seeding machine in the trade display of the conference which looked like it came from New Zealand, so the Canadian industry obviously has some knowledge of our techniques. The continuous ropes, up to 5000 m in length attached to the backbone with a suitable tie (snood), are commonly spaced at 700 mm centres and with a drop length of between 4 to 20 m,

Mussel harvesting in Marlborough Sounds

depending upon depth of water and food availability. Electronic counters indicate the need for snoods to attach the culture rope to the backbone. Continuous ropes have improved operating efficiencies but bring with them problems of twisting when they are handled through mechanical haulers. This necessitates untwisting after harvest and or the use of divers to inspect and untwist the ropes in the water. When the final re-seeding takes place many farmers are now sub-surfacing their backbones to between 2.5 to 6 m to minimise the oversettlement, or second set, of blue mussels, a major problem in New Zealand. The larval behaviour of the two main mussel species (*Perna canaliculus* and *Mytilis galloprovincialis)* are different, with the blue mussel dominating the intertidal zone and the greenshell dominating the subtidal. By understanding your area, and subsurfacing for a time, you can avoid costly oversettlement problems.

With extremes of weather and in high current areas this is not always successful and up to 20% of the total crop in the southern regions are discarded as blue mussel oversettlement. In the northern regions blue mussels do not occur, but those areas have other problems such as barnacle oversettlement and a serious fish predation problem from November to April when they simply are unable to re-seed their lines without risking total loss of spat.

Most mussels are harvested by contractors who have purpose-designed vessels capable of harvesting up to 20 tonnes per hour and total loads exceeding 100 tonnes.

Processing Technology

Processing, like growing, has a high degree of mechanisation. Mussels are harvested into bulk bags of approximately 1 tonne capacity and delivered by truck to processing factories, both large and small, where they are stored in chillers at below 7°C. There are specific requirements for the reduction in temperature during the first 24 hours.

Mechanical size grading of the mussels into small, medium and large size categories takes place with those mussels destined for meat being steam cooked and auto shucked.

Half-shell mussels are blanched in a pre-cooker at 85°C to loosen the unwanted byssus thread and then debyssed (de-bearded) mechanically. They then pass through an infrared tunnel where the top shell is heated to achieve abductor and retractor muscle detachment on one side and they are then finally cooked in a water bath to ensure mantle (lip) separation. They then proceed to an opening table where half the shell is removed.

Mussel harvesting in action

Prior to entering the spiral freezer, the mussels are rapidly cooled in 3°C water. After exiting the spiral freezer, a fine water spray coats the mussels with a thin protective layer of ice and the product is shifted to packing rooms.

A medium-sized factory at the peak of the season may process 500,000 halfshell mussels in a 7.5 hour shift whereas the largest factory processes 1.8 million halfshells in two shifts.

Attempts have been made to process blue mussels in New Zealand using the above equipment but these have been largely unsuccessful.

Strict hygiene requirements are observed, HACCP (Hazard Analysis Critical Control Point) programmes have been in place for some time. RMP (risk management plans), which covers all aspects of the operation, are currently being formalised in line with new food hygiene regulations.

Our Ministry of Agriculture and Forestry Verification Agency run a performance-based verification system and processors with a high standard of internal controls have fewer inspections. Most processors have internal laboratories for conducting microbiological analysis and also use accredited outside laboratories for monitoring for pathogens such as listeria.

New Zealand growing waters and processing standards comply or exceed the NSSP (National Shellfish Sanitation Programme) standards set by the United States Food and Drug Administration and also the European Union Standards. While a number of other countries would clearly meet the appropriate standards, we along with Canada and Chile are the only countries in the world at present approved to export live shellfish to the United States market. Our growing waters achieve the appropriate standards and no depuration is carried out.

Product Forms

The main export form is frozen on the half shell which makes up 90 percent of production with the balance being frozen mussel meat (IQF), frozen wholeshell, marinated, smoked, powdered and some chilled and fresh product.

New product forms are being investigated, particularly consumer packs where we believe a large market exists for product that can deliver consistent high quality with consumer confidence.

The New Zealand Greenshell™ mussel has long been marketed as having anti-inflammatory properties with a proportion of the crop being used for this purpose. Many claims have been made over the years particularly for rheumatoid arthritis, osteoarthritis and asthma. No large scale clinical trials have been undertaken.

Future Development

We will continue to progress and refine our automated system of water sanitation, biotoxin monitoring and predictive phytoplankton monitoring as part of a quality programme to ensure that we meet the best world quality standards consistent with having the least impact on the efficient production of Greenshell™ mussels.

At international forums we will continue to press for all countries to maintain the highest possible bacteriological standards to ensure the customer has faith in all mussel products from all countries. We believe that countries which do not routinely test for heavy metal contamination and biotoxins pose an unacceptable risk for our product, as well as an unacceptable risk for all consumers of mussels.

Customer confidence is an important issue for New Zealand and we have invested heavily in its protection. We have largely abandoned the mouse bioassay for detection of shellfish toxins in favour of chemical testing using liquid chromatography with electrospray mass spectrometric detection (LCMS) with this in mind.

The conflict of use of public space for marine farming continues to be an issue in New Zealand as well as elsewhere. Continued promotion of our Environmental Management System will help ensure that our industry will be accepted as a legitimate user of the public resource. New methods to farm mussels in open water off the coast of New Zealand are in the early stages of development. Progress in this area will have significant worldwide application both for farming and in the market place. Our industry, which has had in the past ample supplies of wild spat, has realised that genetic improvement through selective breeding cannot be achieved with wild spat. In the future, advances in hatchery technology are likely to result in genetic improvements to the New Zealand Greenshell™ mussel.

In the Marlborough Sounds, sustainability and total carrying capacity has been receiving increasing attention as overall productivity drops.

The conclusions that are being drawn from the research have not had universal acceptance from farmers who believe the issues are extremely complex and that much more work needs to be done before the carrying capacity models we have seen in New Zealand can be used as a predictive tool for accurately estimating carrying capacity.

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Mussel Farming in the United States

Gordon King and Jorge Cortés-Monroy

Mussels have long been an important part of maritime North American culture, with shells being found in ancient Native American middens. As a commercial product, mussels played an insignificant role until World War II when production rose by over 2000 percent (it returned to historical levels by 1948). In the 1970s production again grew and there was a move from a wild harvest fishery supplied by commercial draggers off the New England coast to the managed bottom culture of mussels and the development of suspension culture systems in both the Northeast and Northwest akin to those used in Spain. In the Northeast, current production is still based largely on bottom harvests with about half the annual production of 7.3 million kg (16 million pounds) being cultured and the other half coming from the wild fishery. Interest in suspension culture is again developing with the use of mussel rafts imported from the United Kingdom. On the West Coast, production of approximately 1.4 million kg of mussels (3 million pounds) comes entirely from suspension culture and the industry extends from San Diego in the south to Seattle in the north. Current areas of development are hatchery-based breeding and production of seed and the further refining of suspension culture techniques. Current issues of concern are the conflict between marine farmers and those involved in upland development.

I will preface this presentation with a quote that is attributed to one of the USA's pioneer mussel farmers, Peter Jefferds of Penn Cove Shellfish in Washington State:

> "Mussel farming is a business that kills you with promise"

Despite the fact that mussels have been an important part of the diet of North American coastal natives for several thousand years, it has only been in the last 30 years that mussels have gained acceptance as a desirable seafood in North American cuisine.

"Mussel farming is a business that kills you with promise"

– Peter Jefferds, Penn Cove Shellfish

Historical Culture of Mussels in the US

Evidence in coastal Native American middens indicates that mussels were an important part of the diet of native people for at least 4000 years.[1] In fact, the Makah Tribe on the tip of the USA northwest mainland not only consumed mussels in quantity but also used the shells of *Mytilus californianus* for tools (e.g., they tipped their harpoons with mussel shells to harvest the grey whale, another important seafood staple). Mussels were also an occasional seafood option for coastal populations over the last century and there were moderate harvests in New England in the years 1887, 1888, 1897, 1901 and 1904 (Lutz[2] points out that records prior to 1920 may be incomplete). A large peak in mussel harvesting occurred in 1908 during an economic downturn and again in the 1940s when mussels were used as an important protein supplement during World War II (production rapidly increased to a peak in 1944, but returned to historical levels by 1948).[2]

Although of interest when considering mussel production, these facts have little to do with mussel aquaculture. Mussel farming has taken place in France since the 13th century—reportedly started by Patrick Walton, a misguided shipwrecked Irish sailor trying to catch seabirds—and in Spain since the 1940s.[3] But it was not until the 1970s that mussels were grown in the USA.

Ed Myers, at Abandoned Farms in the State of Maine, is reported by Lutz [2] as the first mussel farmer in the USA. He is an excellent example of the strong pull that this industry exerts: despite a quarter of a century of frustrating setbacks and many battles, Ed

Female *Mytilus galloprovincialis*
(photo courtesy of Ian Jefferds)

retains his belief in and ties to the mussel industry. Ed's initial efforts were followed by those of the Jefferds family at Penn Cove on Whidbey Island in the State of Washington and by the Blue Gold company in Rhode Island.

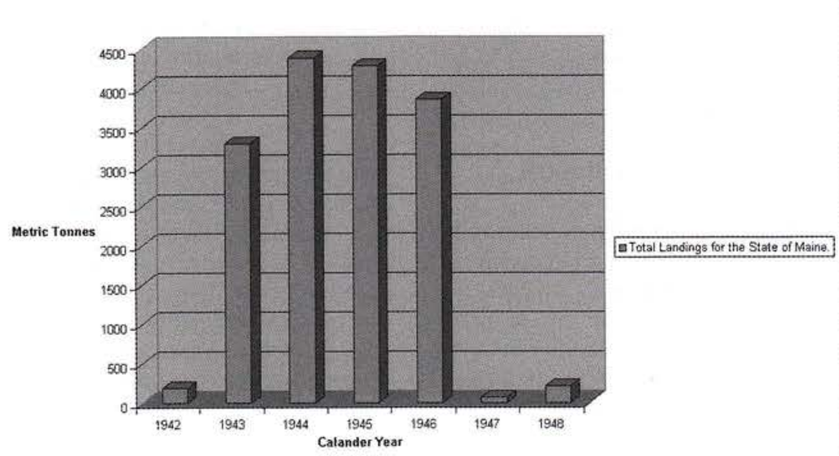
Cultured Mussel Species

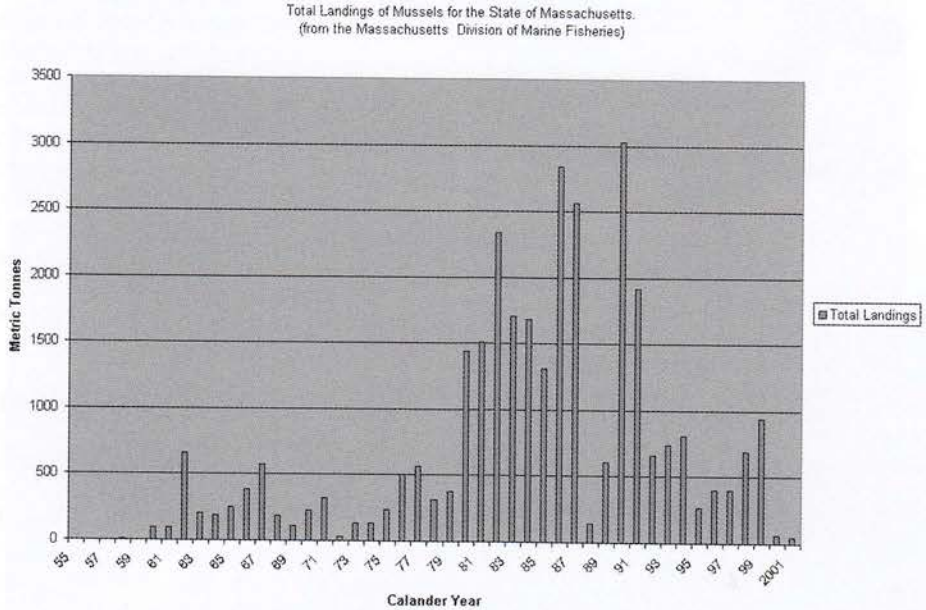
Three species of mussels are cultured and sold in the USA: *Mytilus edulis* in New England, *M. trossulus* in Alaska, both *M. galloprovincialis* and *M. trossulus* in Washington State, and *Mytilus galloprovincialis* in California. There is still a dispute as to the exact taxonomic grouping of these species throughout the USA and to their relationship to mussels of the same name in other parts of the world.(3-5)

East Coast Mussel Culture

On the East Coast, initial interest was in the suspension culture of mussels, similar to that practiced in Spain. But the difficulties of battling ice, predation by ducks, and competition from an abundant supply of cheap dredge mussels off the New England Coast, eventually pushed the industry to explore a system more similar to that used in the Netherlands, i.e. "bottom culture"

The seafood company Great Eastern Mussels of Damariscotta, Maine, promoted this system of culture when they found that with careful management they could produce a good quality product on the seabed. The method is based on assessing the age and density of the mussel beds. If the mussels in the bed are sufficiently young and have a low incidence of pearls, the crop is harvested for sale or the mussels are transferred to leased fattening beds and relayed at a lower density to provide optimum growing conditions and later harvest. Carter Newell of Great Eastern developed the nutrient modeling software "MUSMOD" to assess the carrying capacity of the various beds. Great Eastern also has holding tanks in their plant to allow the mussels to purge prior to sale. Their bottom culture system has been the mainstay of the mussel industry in New Eng-





land for 20 years. Great Eastern Mussels dominates the industry and produces in the order of 3000 metric tons per year.

Although the growers in New England produce a good quality product using bottom culture, there is the challenge of differentiating between their mussels and those from the wild dredge fishery which are of variable quality. Additionally, Maine limits the area of leased seabed any one company can have and there has been some criticism from environmental groups on the effect dredging may have on the benthos and other marine animals. To address these problems, to expand their production, and to meet the challenge from Canadian mussel producers, the Maine mussel farmers are again turning their energy to developing suspension culture.

Suspension Culture

Although the suspension culture of mussels had all but died out in New England by the 1990s, raft culture is again developing in Maine. Forty-foot square (12 m) triple pontoon raft systems of Scottish design, sup-

Great Eastern Mussels harvesting barge ("Mumbles")
(photo courtesy of Carter Newell)

Great Eastern's "Mumbles" harvesting a brailer of *Mytilus edulis* in Maine (photo courtesy of Carter Newell)

porting 450 forty-foot (12 m) droppers are being built. The rafts produce up to 45,000 kg (100,000 lb) of mussels on an 18-month cycle.

Individual leaseholders purchase and stock the rafts with wild-caught *Mytilus edulis* seed which are then either harvested by the Great Eastern Mussel Company "Mumbles" harvester and sold through their business in Damariscotta, or the leaseholders market and sell their mussels privately.

West Coast Mussel Culture

The West Coast mussel industry not only produces different species of mussels than New England but has always, except for one attempt to use intertidal longlines, been based on suspension culture. As well as contending with predation by sea ducks, there is also the problem of predation by perch and crabs and there is the common problem of oversets of barnacles. The West Coast farmers grow their mussels over a great range of latitudes, from San Diego in southern California to Alaska in the north.

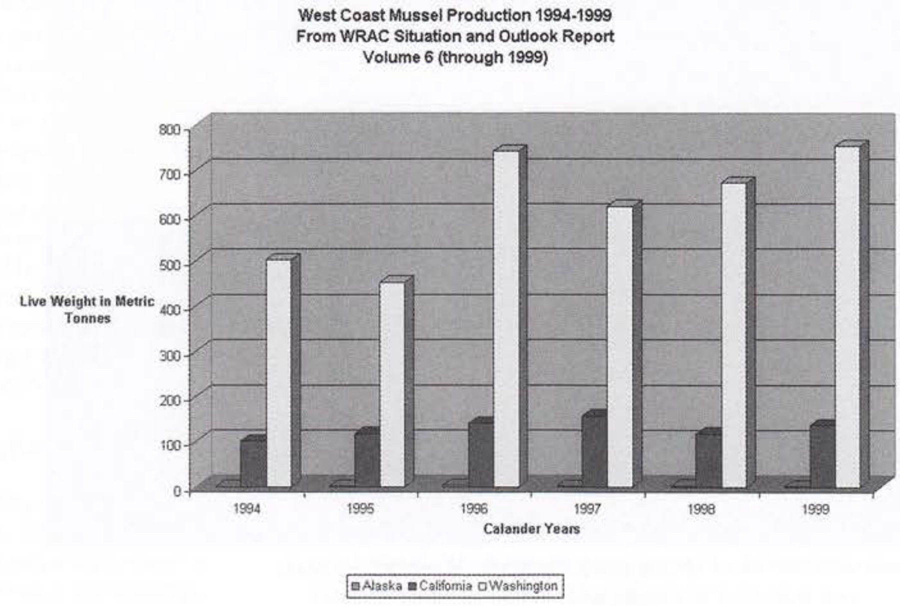
The first west coast farm was developed in the mid 1970s on Whidbey Island by the Jefferds family, who farm there still. They have had to contend with pressure from upland waterfront property owners who did not want their view "polluted" as well as with ducks, perch, and the viral shellfish illness *haemic neoplasia*. This virus infects *M. trossulus* and can kill the majority of the crop prior to

Rafts with trays of concrete weights ready to be added to mussel socks in Gallagher Cove, Washington State

Mussels on dropper at Totten Inlet, Puget Sound

harvest.[7] The disease is harmless to humans, but causes problems for mussel farmers as the crop must be harvested rapidly over a short period of time before it is decimated by the disease.

M. trossulus is a fecund species that produces heavy seed sets in many parts of Puget Sound (Washington State), Alaska, Oregon and California. The disease does not seem to be a problem in the small amount of the species grown in Alaska, but it makes the farming of *M. trossulus* difficult in other states. Several farms were started using *M. trossulus* because growers were seduced by the abundance of free seed. All the opera-



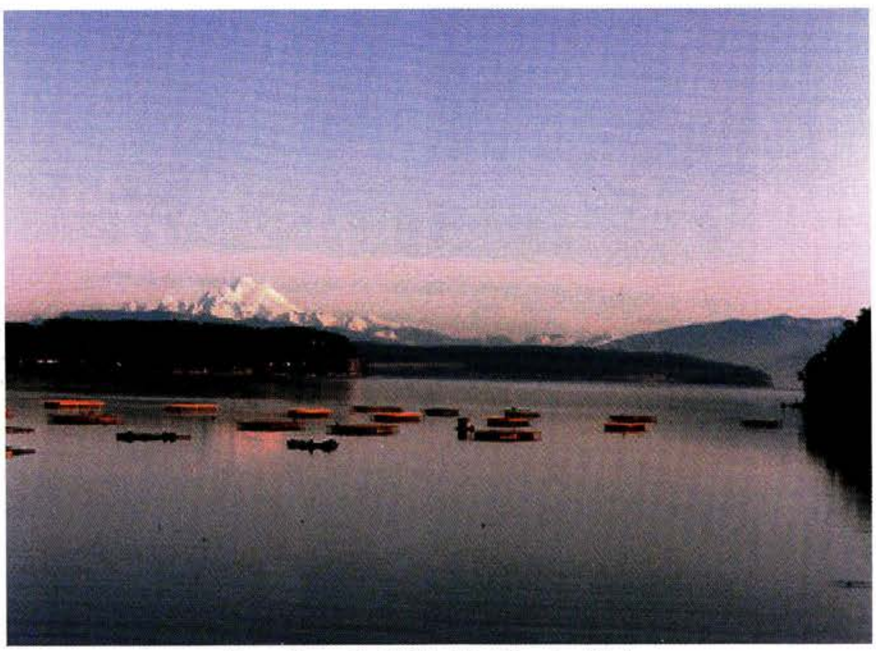
tions, with the exception of the Jefferds farm at Penn Cove, have either gone out of business or have switched to using *M. galloprovincialis* as their mussel of choice. The ability of the Jefferds family to continue profitably farming this species is a testament to their competence, perseverance and the specific environmental conditions in Penn Cove that are favorable for *M. trossulus* culture.

Story of the Mediterranean Mussel on the West Coast

By the 1980s, several mussels farmers in Puget Sound were attempting to grow what they believed was *Mytilus edulis.* Although they had the advantage of cheap local seed, they had a problem with high mortality at maturity. John Richards, a Californian Sea Grant employee on sabbatical in Washington State in 1984, became interested in this problem. John spawned some of the local mussels and was able to produce a small amount of seed. Although fascinating, it did not solve the die-off problem.

Three partners from Kamilche Seafarms, a struggling mussel farm, were inspired by the efforts of John Richards and, being recent graduates of the local liberal college, they had the ability to "look outside the box". They asked Lee Hansen, a hatchery operator in Oregon to spawn some mussels from California. The mussels were set and grown through the nursery stage by Ted Kuiper, a clam and oyster seed grower in northern California. Then Kamilche planted them out in their lantern cages and waited to make money. But by 1985/86 they had decided that their dream of being pioneers in the sea farming business was to no avail and they started pulling their longlines out of the water. To their surprise, while most of the mussels were dead or dying, one patch of mussels was robust and healthy. On examining their records, they found these live mussels were the hatchery mussels they had received from Ted Kuiper in California. Further investigation revealed that the bay mussels on the West Coast were not *M. edulis,* but rather were a combination of species consisting mostly of *M. trossulus* from Alaska south to about central California and then mostly *M. galloprovincialis* in southern California. It became apparent that most of the growers in Puget Sound were growing *M. trossulus* and that Kamilche Seafarms had inadvertently imported *M. galloprovincialis* from California.

M. galloprovincialis is different from *M. trossulus* in several ways. It can live for several years, is generally larger than *M. trossulus* and has a thicker and shinier shell. The byssal threads are not as numerous as in *M. trossulus* and they have both pink/orange and creamy white gametes compared to just the creamy white gametes of *Mytilus trossulus*. One other significant advantage when marketing *M. galloprovincialis* is that the mussels are at their strongest and sweetest during the entire summer when many other shellfish are spawny and have a short shelf life. These factors make *M. galloprovincialis,* as a general rule, a preferable species to farm over *M. trossulus.*



Penn Cove Shellfish, Washington State
(photo courtesy of Ian Jefferds)

Luckily for Kamilche Seafarms, there was a steady supply of *M. galloprovincialis* seed from Ted Kuiper in California until the early 1990s, by which time two Puget Sound hatcheries, Taylor United and Coast Oyster, had started producing mussel seed for sale. At the present time, except for a small production of *M. trossulus* in Alaska, all the mussel farmers on the West Coast grow *M. galloprovincialis.* The exception is Penn Cove, which still reserves about three-quarters of their production for *M. trossulus* grown from wild seed.

Apart from the small growers in Alaska on the USA west coast there are only 4 commercial growers in Washington State and 3 in California which consistently grow mussels. All the *M. galloprovincialis* grown in Washington is from hatchery-produced seed while the growers in California use mostly wild *M. galloprovincialis* seed.

California

In San Diego, John Davis farms in a lagoon using longlines on which he hangs short ropes of mussels. While using mostly wild seed, he has recently been experimenting with hatchery seed. In the early 1990s John had to face the added problem of high coliform counts in his growing waters. To circumvent this problem, he now runs a depuration system.

The other main mussel company in California, Eco Mar, is experimenting with sub-surface grow-out systems but most of its production is obtained by scraping mussels off oil platforms.

These two mussel farms produce a total of 150,000 to 200,000 kg mussels in an average year.[9]

Washington State

As in many marine farming areas in the USA, Washington State has seen a succession of mussel growers come and go. Many started with a starry- eyed belief in the brave new world of marine farming. A few remain to make living from the business. Whether the survival of their businesses is due to luck or good management is probably variable and debatable.

As mentioned earlier, the original mussel grower in Washington State was the Jefferds family of Penn Cove on Whidbey Island. The Jefferds family started

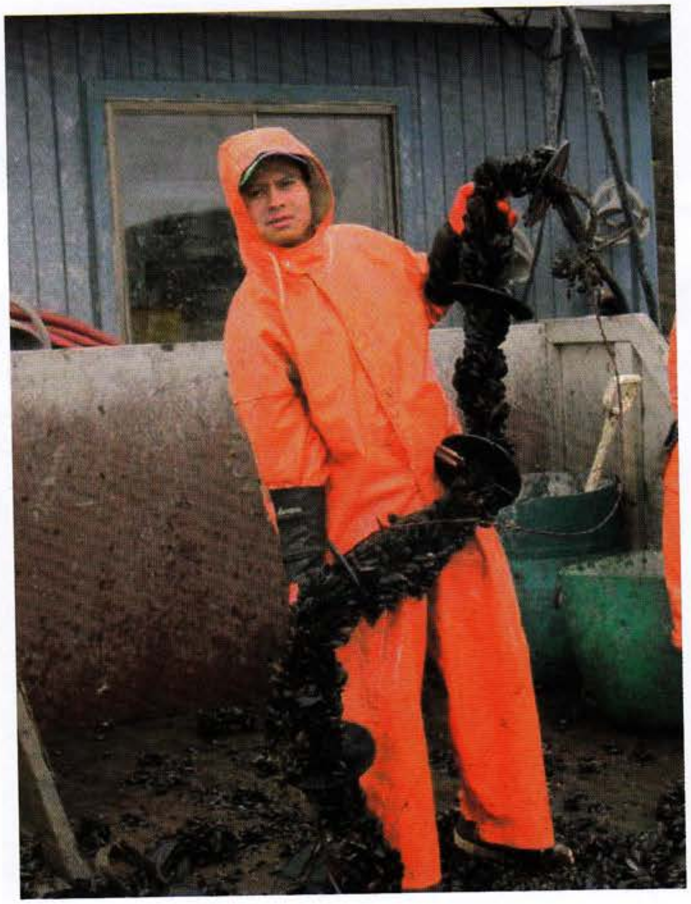
Upwelling nursery at Taylor United Hatchery in Dabob Bay, Puget Sound

Emily Merwin checking larvae in 40,000-liter tanks at Taylor United Hatchery, Dabob Bay

Mussel rafts at Gallagher Cove, Puget Sound

with cedar rafts and then tried longlines, but have since returned to using large rafts. Ian Jefferds, who presently runs the company, has carried on the family tradition of walking the line between the conservative approach of sticking with what works and the need to dynamically adjust techniques to survive into the future. This is exemplified by his continued use of *M. trossulus,* which his father started with, and adding hatchery-produced triploid *M. galloprovincialis.* Ian has also recently improved on the pegs used by the Spanish to decrease mussel slippage on the ropes by manufacturing a spiked plastic disk that is inserted into the rope.

Kamilche Seafarms, in southern Puget Sound, is notable in that it helped pioneer the use of hatchery mussel seed. They use a system of modified lantern nets and longlines to grow mussels by placing the mussel seed on pot-scrubber substrate at various levels within a lantern cage and covering it with an extruded plastic mesh sleeve.



Mussel dropper with Mussel Discs™ inserted (photo courtesy of Ian Jefferds)

The other large mussel growing company in Washington State is Taylor United Inc. Taylor United started experimenting with mussel growing in the late 1980s after watching the success of their neighbor, Kamilche Seafarms. After initially buying seed from Ted Kuiper in California, the company started experimenting with mussel spawning and nursery systems in their newly-built bivalve hatchery on Dabob Bay in Puget Sound. They confirmed that, as suggested by Kamilche Seafarms, the waters of southern Puget Sound are well suited to growing *M. galloprovincialis.* Product is being harvested in less than 18 months from spawn.

Taylor's production has grown steadily from a few thousand kilograms in 1990 to over 400,000 kg of mussels a year that are sold throughout the USA and Western Canada. Their grow-out technique is similar to others in the USA and throughout the world. Seed is socked in either a knitted or extruded plastic sock and hung on a netted raft until harvest. At harvest, the ropes are dropped onto a submersible platform which is then raised and the mussels are transferred into insulated totes and transported to the plant where they are washed, declumped, packed and shipped. Perhaps the most significant difference of importance in their operation is the use of hatchery techniques to produce seed.

Hatchery Mussel Seed

Washington State is one of the few places in the world where the mussel industry is based on hatchery-produced seed. The only other countries that have used hatchery seed are Australia (Tasmania) and China.

Producers in Washington State were forced into hatchery production of mussel seed because there is a very limited natural set of *M. galloprovincialis* in state waters and the more prolific *M. trossulus* is difficult to culture profitably.

Hatchery production of *M. galloprovincialis* seed is similar to that of clams and oysters. In Washington State, the mussels are sufficiently ripe to spawn from August until March. The mature mussels are either cleaned and hung as a group in larval tanks to spawn naturally or, for specific crosses and triploid production, they are spawned in trays and individual containers and then separated into separate genders. The gametes are checked for correct identification and the sperm and eggs are then combined. To produce triploid mussels, the fused eggs and sperm are treated with chemicals (cytochalasin or 6-dimethylaminopurine) or heat shock.

Once spawning is completed, it usually takes about 24 hours for the larvae to reach the straight hinge stage and 13-14 days before they set. The larvae can be set on 160-micron down-well screens or directly on substrate in well-aerated setting tanks.

At a size of about 1 mm (6 weeks of age), the seed is put on fiberglass window screen frames and transferred to a passive ocean nursery (i.e., a netted cage) until the seed is 6 to 10 mm, at which stage it is put into its final grow-out socking.

Future for Mussel Production in the USA

Although the development of raft culture in Maine looks promising and there are experimental projects on submerged longlines in offshore New England waters it is hard to see massive growth occurring in the mussel industry in the USA. The coastline, especially sheltered coastline, is a limited and valuable commodity. Real estate development, pressure from pollution and the need to share the natural environment with many threatened or endangered species makes acquisition of suitable new growing areas an expensive and challenging proposition.

The recent discovery of populations of *Perna viridis*[(10)] in Florida and *P. perna* in Texas leave open the possibility of future development of green mussel culture in the southeastern USA. *P. viridis* is cultured extensively in the western Pacific region, supporting a healthy industry in several countries.

Because of the abundance of food in North America, mussel production seems to be seen by the general public as of little importance. This perception often leads regulatory and permitting agencies to make it difficult for the industry to develop, or they even discourage development. The industry needs to persist in its efforts to educate the public on the importance of water quality and the role marine shellfish farmers play in maintaining high quality water.

On a more positive note, North America is one of the richest markets in the world and clearly our access to that market is a prize well worth preserving. With continued production of quality product and hard work to ensure that the end user eats a fresh and tasty mussel, sales should continue to grow.

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Overview of the Galician Mussel Industry

Bahir Keldany

The history of mussel culture in Spain dates to the 1700s, but the real development of the industry began in the 1940s. Today there are over 3300 floating mussel nurseries in the ria waters of Galicia, making it one of the major mussel-producing areas in the world. In 2001, Spain produced 250,000 metric tons of mussels, 40% of the total European production.

Galician Mussels

The Galician mussel *(Mytilus galloprovincialis)* is a bivalve mollusc that lives in the wild, forming quite numerous communities in shallow coastal areas. They are attached to rocks by the byssus. The same method of attachment is used by Galician cultivators to attach the mussels to ropes hanging from floating nurseries (bateas) in order to achieve a high quality mussel, with a good yield of meat and free from sand and fungus.

The mature male mussel releases its sperm into the water, fertilising the mature ovules inside the female. The larvae that are produced, around 800,000 per female, live deep in the sea for a few days until they develop. They later attach themselves to a particular location by a bundle of fibres called a byssus.

The Galician mussel is axe-shaped, pointed and thick at the front, and long and sharp at the back. Its shell is made up of two identical (bi-valve) shells made of calcium carbonate, covered externally by a bluish black coat, with concentric growth lines grooved into the shell. A dorsal hinge called a "charnela" connects the two shells

The inside of the mussel, referred to as "El Manto" normally has an exceptional and very characteristic creamy-orange colour, quite different from the white variety found in other areas or other parts of the world.

The Galician mussel feeds on phytoplankton which it filters from sea water. Its filtering capacity is exceptional, up to 8 liters of water every hour.

As far as foods go, the Galician mussel has excellent protein and nutritional value similar to that found in hake, lobster and the majority of other edible seafood.

Table 1. Nutritional value of Galician mussels.

Protein	10.4 g
Fat	1.9 g
Carbohydrate	1.9 g
Water	85.4 g
Iodine	0.035 g
Calcium	80.0 mg
Iron	4.5 mg
Magnesium	23.0 mg
Vitamin B_1 (thiamine)	0.1 mg
Vitamin B_2 (riboflavin)	0.14 mg
Vitamins A, C and D	trace amounts
Calories	62

Nutritional Value

The Galician mussel is a well–balanced, healthy food. Rich in proteins, vitamins and minerals, the Galician mussel is ideal for all types of diets, including those low in calories (Table 1). Mussels are suitable for youngsters and generally for anybody desiring a healthy life. They are also low in cholesterol and are good for bones and muscle co-ordination.

A dozen Galician mussels has about 150 g of meat; 100 g of mussel meat provides up to a quarter of the daily protein needs of adults.

The "El Manto" of the Galician mussel is a distinctive orange color

The bateas (floating nurseries)

Table 2. The open-air mussel is protected by the "Denominación de Origen Protegida Mejillón de Galicia-Mejillón" of Galicia and can be presented in two varieties that are distinguished by the labels:

ESPECIAL-1 (E-1):	up to 23 pieces per kilogram
ESPECIAL-2 (E-2):	from 24 to 27 pieces per kilogram
NORMAL-1 (N-1):	from 28 to 32 pieces per kilogram
NORMAL (N-2):	from 33 to 40 pieces per kilogram

The Galician mussel guarantees a good yield of meat making it a first class quality product for both its size and its meat

Sector Description

The mussel sector, with 3337 floating nurseries (bateas), directly creates some 11,500 jobs (8500 of which are permanent) and indirectly creates 7000 others and has an annual turnover of 385 million euros (approximately Can$540 million), representing a very important industry in the present and future economy of the Galician community.

Its socio-economic significance is also gauged by the multiplying effect derived from the distribution of income generated by this activity. As a result, the mussel industry has a major influence on the economy, on employment, and above all on the future development of some areas of the Galician estuaries.

History

Galicia's link with molluscs and specifically with the mussel is indisputable, but since its first inhabitants took advantage of the low tides to obtain a rich seafood menu, things have changed greatly. No longer is the harvesting of mussels a simple process. Galicia has become a leading cultivator of mussels in the world of aquaculture and the industry forms the mainstay of the economy for many coastal boroughs.

The history of mussel cultivation began in the middle of the 18th century when the marinating Galician oyster was at its peak. At that

Mussel producing areas in Spain

time, cultivation didn't exist in any strict sense; the wild mussel was simply collected from certain parks or zones and harvests were subject to the permission of some families.

Mussel cultivation started to grow and to gain importance in the 19th century when the first experiments on cultivation were carried out. Don Paz Granells says that in Carril (Ria of Arousa) in 1896 the shellfish gatherers turned the old oyster beds into mussel beds.

During the first decades of the 20th century efforts intensified to establish a stable cultivation of mussels in enclosures or on posts. But it wasn't until the 1940s that the real development of Galician miticulture began. When Señor Ozores Saavedra, Lord of Rubianes and Marquis of Aranda, who owned "Viveros del Rial" attempted to raise mussels on posts, he soon changed his approach and began cultivating mussels by floating them.

The first floating nursery was anchored in the Ria of Arousa in 1945. This prototype had a single float that was cube shaped and made from wood. The float supported a wooden framework from which a few meters of esparto grass rope were hung. The results achieved by this pioneer of Galician miticulture were so encouraging that in the following year 10 floating nurseries were anchored in the jetty at the port of Vilagarcía de Arousa.

The next decade was a period of expansion for Galician miticulture. In 1949 nurseries were anchored in the Ria at Vigo and by 1954 they extended to Cambados, O Grove, Bueu, Redondela and Pobra do Caramiñal. In 1955 nurseries were anchored at Sada and finally in 1956 they reached the Ria at Muros.

During these years the structures and working methods used to culture mussels were continually being improved. The wooden crates were covered with cement to prolong their life, and the esparto grass ropes were replaced by nylon ones. The size of the framework was increased when the industry began to use straps of metal cable to support the structure. Some producers even adapted old boat hulls and floated them.

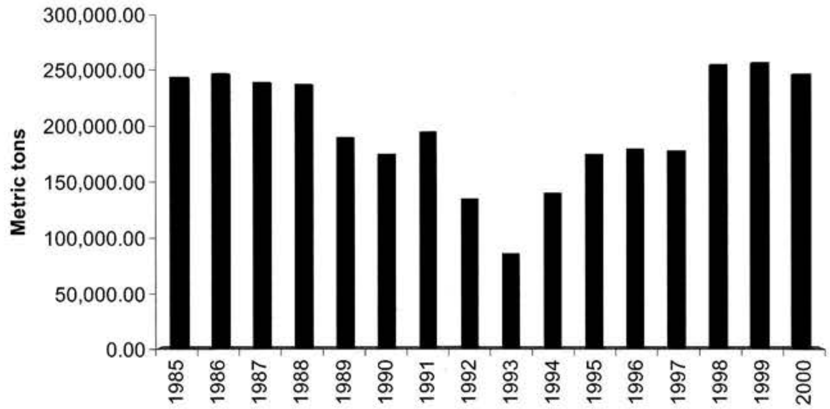
Today in the Ria waters of Galicia there are more than 3300 floating nurseries dedicated to the cultivation of mussels and these make our community an aquaculture power on the world-wide stage

Philosophy of Cultivation

The philosophy that the mussel culture industry has maintained since the beginning of cultivation efforts has the following features:

1. Maintenance of the ecological production model based on the family economy, while allowing the competition necessary to guarantee quality to the consumer at an affordable price.
2. Carrying out aquaculture in tune with the environment using non-aggressive technologies and incorporating new innovations based on the extensive research that is being done.
3. Using no genetic manipulation or biotechnology whatsoever. Scientific inspections are done to ensure that the product is totally harmless and specifically adapted to the consumer's health.
4. Culturing mussels extensively in the highly productive Galician estuaries without manipulating the environment or providing artificial feeding. Simply placing the mussels on the cultivation

Floating mussel nurseries in the Ria waters of Galacia



Production of cultured mussels, 1985-2000

ropes is the most efficient way of ensuring they obtain the best nourishment from the sea (the phytoplankton).

5. Guaranteeing the health of the Galician mussel. There is no use of medicines, vaccines or other pharmacological or chemical products, preventative or curative, in its cultivation and handling.
6. Harvesting and marketing the Galician mussel fresh, with no added preservatives. Only 100% recyclable containers are used in the marketing of the mussels.

In summary, the industry recognises the right of all consumers to have access to a product of very high nutritional quality at the most reasonable price.

Composition and Activities

The Regulatory Council for the Galician Mussel is made up of representatives from the producers, businesses and dispatch centres, as well as technical committees from the Council of Fishery, Seafood and Aquaculture and the Health Department from Galicia's local government. Efforts to establish this organisation began in 1989 and in October 1994 the Regulatory Council started to operate. Its basic functions are:

- To regulate mussel culture activities and establish the characteristics that should be present in the product to ensure it surpasses the standard that will satisfy the consumer;
- To ensure the regulations are adhered to;
- To guarantee, by means of a distinctive label, that the product the consumer buys is of very high quality; and
- To promote and value the product.

To carry out these functions to as high a standard as possible the Regulatory Council also undertakes addi-

Table 3. Characteristics of the estuaries where mussel cultivation is carried out.

Ria	Vigo	Pontevedra	Arousa	Muros-Noia	Ares-Betanzoa
Length (km)	33	23	26	12	19
Area (km^2)	175	145	230	120	72
Volume (m^3)	3100	3240	4300	2700	750
Maximum depth (m)	42	40	65	46	40
Rivers	Oitavén Lagares	Lérez	Ulla Umia	Tambre	Eume Mandeo

Table 4. Distribution of the mussel sites and trays by estuaries.		
Ria	**Mussel Sites**	**Percentage of Trays**
Ares-Betanzoa	2	3.09
Muros-Noia	4	3.54
Arousa	36	68.89
Pontevedra	7	10.37
Vigo	14	14.32

tional activities such as training, scientific research, and market research.

Floating Nurseries

The cultivation of the Galician mussel takes place in a floating nursery, which is a floating tray made up of a more or less rectangular wooden eucalyptus frame on which the ropes of mussel are tied and then floated. The nurseries used in Galicia consist of:

A ***shackle,*** which is a framework of wooden bars over which the ropes of the crop hang. They are more or less rectangular in shape and cover a maximum area of 500 m^2.

The ***flotation system*** has varied greatly over time. The first floats were hulls of old boats or wooden buckets. These were gradually replaced with polyester tubular floats or cylindrical floats made from iron sheet metal coated with polyester.

The ***tray of the holding system*** is anchored by means of one or two chains joined to a concrete block called "muertos" (dead).

Harvested mussels

Shackle of a floating nursery

Table 5. Data on Mussel Production from the UN Food and Agriculture Organization (FAO).

Total production (fished and cultivated in metric tons (millions)).

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
World	1.333	1.327	1.338	1.316	1.264	1.353	1.299	1.355	1.587	1.678	1.557
EU	0.593	0.623	0.589	0.551	0.597	0.624	0.634	0.567	0.769	0.767	0.720
Spain	0.173	0.197	0.139	0.091	0.143	0.182	0.188	0.189	0.261	0.262	0.128

Spanish production as a percentage of World and EU production (%).

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
World	13.0	14.8	10.4	7.0	11.3	13.5	14.5	13.9	16.5	15.6	15.9
EU	29.2	31.6	23.6	16.6	23.9	29.2	29.7	33.3	34.0	34.2	34.4

Aquaculture production (million metric tons)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
EU	0.464	0.454	0.412	0.367	0.422	0.457	0.498	0.492	0.600	0.599	0.547
World	1.087	1.074	1.062	1.048	0.985	1.109	1.095	1.115	1.337	1.441	1.318
Spain	0.173	0.195	0.139	0.091	0.143	0.182	0.188	0.189	0.261	0.262	0.248

Spanish cultured production as a percentage of World and EU production (%).

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
World	15.9	18.2	13.1	8.7	14.5	16.4	17.2	16.9	19.5	18.2	18.8
EU	37.4	43.0	33.7	24.9	33.7	39.8	37.8	38.4	43.5	43.7	45.2

Table 6. Data on exports from ICEX (Spanish Institute of Foreign Commerce).

Export		1996	1997	1998	1999	2000
Fresh	tons	19,240	20,549	20,157	22,215	19,535
	million ptas.	1741	2154	2390	2703	2410
Canned	tons	1045	1032	1021	1203	1200
	million ptas.	702	596	709	846	853
Frozen	tons	2674	3189	4000	4825	4723
	million ptas.	862	1076	1048	1561	1407

The ***cultivation system*** consists of a maximum of 500 ropes no longer than 12 m in length, knotted to the shackle. To distribute the weight of the rope and avoid the detachment or collapse of the mussels, the rope is crossed every 40 cm by sticks or plastic strips called "tarugos" (pegs) or "palillos" (thin sticks).

Cultivation Technology

The Galician mussel is produced using floating nurseries in the estuaries. This method of production is the best approach for guaranteeing excellent yields, which is demonstrated by the 250,000 tonnes of mus-

Table 7. Data on imports from ICEX.

Imports		1996	1997	1998	1999	2000
Fresh	tons	3090	3283	5339	5564	5984
	million ptas.	385	458	844	957	1295
Canned	tons	683	581	595	415	439
	million ptas.	480	580	550	425	417
Frozen	tons	1200	1648	3298	2669	1916
	million ptas.	434	646	1322	1064	1024

sels marketed yearly in Galicia (40% of the European production of this mollusc).

The cultivation process involves the following stages:

Obtaining Seed

The first step in the cultivation of mussels is collecting the seed, or "mejilla", from coastal rocks or traps. In the months from October to April the producers use scrapers to remove the mussel seed that settled naturally on rocks. Alternatively, from March to June they hang rope traps from trays to catch mussel larvae as they settle.

Binding

Mussel seed of a size of 1 to 2 cm are transferred to trays or to a boat and the preparation of the "ropes of the seed" proceeds. The baby mussels are wrapped around the rope with the help of a fine rayon net which decomposes within a few days of being placed in the sea, ample time for the mussels to fix themselves to the ropes. This operation can be done either manually or using a binder, which is a machine specially designed for this purpose.

Splitting

After 4 to 6 months, when the mussels reach a size of 4.5 to 5.5 cm, the ropes of seed are removed from the water. Due to the considerable increase in the weight of the mussels, it is necessary to split the ropes and create new ropes which are less thick. Splitting the rope not only helps the mussels to grow, it also ensures that the mussels do not detach themselves from the ropes. For each "rope of seed", two or three split ropes are obtained, which are put back into the sea until the mussels reach market size.

Collection and Sorting

After approximately one year, the mussels reach market size. The ropes are removed from the water with the help of a crane and are put onto a boat. Once under cover, the mussels are cleaned with plenty of seawater, sorted according to size, and put into plastic bags. They are now ready to go to the dispatch centres for subsequent marketing.

Mussel ropes being removed from the water

The harvest period for the Galician mussel depends, amongst other things, on its destination. Mussels destined for the canning and processing factories (65% of the total) are generally gathered in the summer, whilst it is better for those destined for fresh consumption (35% of the yearly production) to be gathered during the autumn and winter.

Economical and Commercial Aspects of the Sector

The importance of the mussel industry to Spanish fisheries and aquaculture production and its evolution during the last 30 years is highlighted by the fact that in

1972 mussels represented a value of 12% of the marine production and nowadays their value represents 23% of the above mentioned production.

Recently, several marketing studies have been carried out in relation to bivalve molluscs, particularly mussels. There is a prediction of expansion of mussel culture in Europe. Increase in demand will occur either in the traditional market or in the segment of value-added or transformed products integrated on the line of new technologies of conservation and production, but not in the fresh markets.

With respect to mussel production in Galicia, the market trend is similar:

- Maintenance, with a slight increase, of the level of consumption of fresh mussels (prices jumped from 4.5 cents per kilogram in 1972 to 79 cents per kg in 2001);
- Stable demand for canned products;
- Significant increase in the consumption of frozen mussels used in refrigerated and prepared food.

In 2001, Spain exported almost 30,000 mt of mussels, 22,000 mt of fresh mussels, 3000 mt of canned mussels, and 4700 mt of frozen mussels.

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Official Institutions in Spain

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http://www.xunta.es/conselle/cma/index.htm

Consellería de Pesca e Asuntos Marítimos—Xunta de Galicia
http://www.xunta.es/conselle/pe/index.htm

Junta Nacional Asesora de Cultivos Marinos (JACUMAR)
http://www.mapya.es/jacumar/jacumar.asp

Research and Development

Centro de Control do Medio Mariño—Xunta de Galicia
http://www.cccmm.cesga.es/Index.htm

Centro Internacional de Investigación dos Recursos Costeiros
http://www.upc.es/ciirc

Centro Técnico Nacional de Conservación de Productos de la Pesca (CECOPESCA)
http://www.anfaco.com/externo/

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http://www/seui.mec.es:8011/cytmar/indice_CYTMAR.html

Parque Tecnolóxico de Galicia
http://www.ptg.es/cgi-bin/www/home.pl?c

Universities

Fundación Empresa Universidad Gallega
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Development of Mussel Aquaculture in China

Tang Qisheng, Fang Jianguang and Liu Hui

Mussels are the main marine bivalves cultured in China. Mussel culture began in the 1970s and rapidly developed in the early 1980s when farmers mastered the technologies of breeding, seed collection and longline culture. Due to the low economic value of mussels compared with oyster, scallop and shrimps, the development of the industry began to slow down in the early 1990s. More than 50 species of mussels are found along the coast of China. The most important species being cultured are the blue mussel, *Mytilus galloprovincialis* Linne, the green mussel *Perna viridis* Linnaeus, and the thick shell mussel *Mytilus coruscus* Gould. Mussels are cultured by three basic methods: rope culture, lantern net culture, and bottom culture. Rope culture is the most popular method. In 2000, the annual yield of cultured mussels in China was 534 thousand metric tons, about 6% of the total shellfish production in China. To maximize the economic and ecological benefit from marine culture, polyculture of mussels and macroalgae, especially with the kelp *Laminaria japonica,* has been developing in the north of China since the mid 1980s. At first, farmers merely increased the culture densities of both kelp and mussels in an effort to produce as much product as possible and the results were not as good as expected. By the mid 1990s results had greatly improved because strategies were refined using information from studies on the carrying capacity of the culture sites. During the spring and fall, large numbers of juvenile mussels foul the culture facilities of other species, blocking the mesh of lantern nets used to grow scallops and cages used for fish culture. The fouling negatively influences the growth and survival of these species, and the fouling of mussels on longlines increases the weight of the lines and thus the labor cost. How to control the fouling of mussels on marine culture facilities has been and still is a challenge for scientists and farmers in China.

General Introduction

The practice of mussel aquaculture and seed collection began in 1958 in China; in 1966 experiments on raft-culture of mussels succeeded. Since then, mussel aquaculture has developed rapidly, especially in northern China, where production reached 32,500 metric tons in Dalian city (Liaoning province), and the raft-culture area totaled 20,000 mu (13.33 km^2) in Shandong province in 1976.

Since 1973, some provinces in southern China, including Fujian, Zhejiang and Guangdong, have experimented with the transplant of *Mytilus edulis* and success has been reported in several localities.[5] At the same time, the indigenous species (*M. galloprovincialis* and *Perna viridis*) and *M. coruscusa* were also under study, and progress has been achieved on artificial reproduction,[1,2] seed collection and on-growing experiments.

Since the success of experiments on the hatchery reproduction of *M. edulis* in 1958, the technology for artificial reproduction has improved significantly. Production of *M. edulis* seed has reached 3 million individuals/m^3, and 80,000 to 120,000 individuals/m^3 for *P. viridis*. Noteworthy is that several batches of seed can be produced each year and the total production has been improved several fold. In addition, the success of cross-fertilization of *M. edulis* and *P. viridis* in Guangdong province has enriched our experience on mussel breeding.

Biological and Ecological Characteristics

Mussels are widely distributed species. Blue mussels *(M. galloprovincialis)* were originally distributed only in the Bohai Sea and Yellow Sea, but they have survived in the Eastern China Sea and Southern China Sea after they were transplanted. The thick shell mussel *(M. coruscus)* is distributed in the Yellow Sea, Bohai Sea, Eastern China Sea and Taiwan regions. The green mussel *(P. viridis)* is a warm water species and is only distributed in Eastern China Sea and the

Table 1. Fecundity of different species and body sizes of mussels.

Species	Shell Length (mm)	Number of Eggs in Single Ovulation (millions)
	4-6	0.3-6
Mytilus edulis	8-10	5-15
	largest size observed	25
Perna viridis	9-11	16.96-31.1
Mytilus coruscus	11	9.1-24.2

Southern China Sea.[7]

Reproduction

Fecundity

The fecundity of mussels varies within and among species (Table 1). Generally speaking, larger broodstock mussels tend to produce more eggs than smaller ones. Sexually mature individuals can reproduce every year.

Season of reproduction

The reproductive season of mussels is relatively long and usually continues for several months (Table 2). But the primary reproductive period generally occurs in the spring and summer and lasts for 1 to 2 months. The timing of reproduction is influenced by various factors, so that different species spawn in different seasons. Within species, there is geographic variation in the reproductive season because of differences in local environmental conditions.

Embryo development

Listed in Table 3 is the length of time that the three mussel species spend at each embryo and larval development stage under different water temperatures.[7]

Effect of environmental factors on embryo development

Water temperature. Water temperature has a major effect not only on survival, but also on embryo development and growth. The optimum temperature for embryo development varies with species and for *M. edulis* is 12°-22°C; 22°-28.5°C is better for *P. viridis*, and 8°-13°C is optimum for *M. coruscus* in Shandong province.

Salinity. Embryos of *P. viridis* cannot develop normally in salinities greater than 22.0-32.4‰ (specific gravity 1.016–1.024), while the optimum threshold is 23.59–31.1‰ (specific gravity 1.018–1.023). Although the optimum threshold for *Mytilus edulis* is 23.3-32.4‰ (specific gravity 1.017–1.024), artificial reproduction of this species is usually carried out in northern China under 27.2–32.4‰ (specific gravity

Table 2. Reproductive season of mussels.

Species	Spawning Season	Peak of Reproduction	Locality
Mytilus edulis	April to June	April and May	Liaoning Province, Northern China
	September to November	September and October	Shandong Province, Northern China
Mytilus coruscus	March to September	late April to late May	Shandong Province, Northern China
Perna viridis	April to November	May and June	Haifeng, Guangdong Provinces, Southern China
		October and November	Xiamen, Fujian Provinces, Southern China

Table 3. Rate of embryo and larval development of three mussel species (time to reach the various developmental stages)

Developmental Stage	*Mytilus edulis* (16° to 17°C)	*Mytilus coruscus* (13° to 21.3°C)	*Perna viridis* (22° to 28.5°C)
2-cell stage	70 min	65 min	27 min
4-cell stage	85 min	85 min	36 min
8-cell stage	3 h 20 min	1 h 45 min	45 min
Morula	4 h 40 min	2 h 5 min	50 min
Blastophore	7 h 20 min	5 h 17 min	2 h 40 min
Gastrula	9 h 20 min	–	3 h 10 min
Trochophore	19 h	11 h	7-8 h
Veliger	40 h	27 h	16-18 h
Umbro larva	8 d	10 d	5-9 d
Metamorphosis	20 d	20 d	16-24 d
Settlement	25 d	25 d	20-27 d

Table 4. Effect of water temperature on the time required for fertilized mussels to reach the veliger and settlement stages.

Species	Temperature (°C)	Fertilization to gastrula	Fertilization to veliger	Fertilization to settlement	Size at settlement
Perna viridis	22.5-27.8	4 h 5 min	19 h 45 min	23 d	
	18.5-22.5	9 h	27 h	60 d	
Mytilus edulis	18.4-21.0	12 h 30 min	34 h 30 min	20 d	
	11.0-17.5	24 h	48 h	29 d	217-317
Mytilus coruscus	18.5-19.0	11 h	27 h	25 d	
	17.0	20 h	41 h	40 d	

1.020–1.024).

Salinity may affect mussel larvae during the period of fertilization, embryo development and settlement. Extreme salinity has been reported to have a negative effect on mussel reproduction both under artificial and natural conditions.

Light intensity. Different species of mussels may need different intensities of light during their embryonic development. Unfavorable light intensity can have a negative influence on larval growth. Deficient light can slow the growth rate, while excessive light can cause the larvae to sink and die. It is very important to avoid direct or intense scattering sunlight.

It has been reported that pelagic larvae of *Mytilus edulis* develop normally under 800 to 1200 lux. At this intensity, photosynthesis of phytoplankton and levels of dissolved oxygen are improved, the level of ammonia is reduced, and the water quality is enhanced generally. Growth rate of the mussels was slow under 200 lux, only 1/30 to 1/2 of that in larvae grown under 1000 lux. Under 4000 lux, all activity stopped and the larvae sank to the bottom. Mass mortality occurred under 11,500 lux.

The preferences for light intensity may change with the stage of development. For example, Umbro larvae prefer 500 to 1500 lux, while metamorphosis larvae prefer less intensity, and even lower intensity is more optimal for larvae approaching the settlement stage (200 to 500 lux is enough). Settlement can be accomplished even in total darkness. Darkness can induce beard secretion, so that settlement is also improved. Under natural conditions, more *Mytilus coruscus* seed settle in *Sargassum thunbergi* thickets, crevices of rocks, or shady areas of reefs than in other areas.

Mussel Farming Development — Seed Collection, On-growing and Harvest

Seed collection

Collection and utilization of wild spat

Originally, spat were collected using shovels and spades to scrape juvenile mussels from reefs, embankments, docks and tubes. Baskets and boats were used to transport mussel spat to areas used for growout. Diving and trawling were necessary to obtain seed settled in deep water.

Collected seed were split into bags and hung on the culture rafts from ropes, or were scattered onto rocky sea-beds for on-growing. In this way, a natural growing ground formed within a few years, and natural seed collection could be practiced to enhance the aquaculture of mussels.

Natural seed collection

In natural seed collection, which is also called half-artificial seed collection, special collection instruments are placed at sea in areas where mussel larvae are swarming. The relatively simple equipment, low investment, and the large quantity and fairly good quality of seed collected all characterize this method. It is critical that the time of settlement be accurately forecasted and that efforts be well organized so that a large amount of material and manpower can be put into use at the required time. Because of variation in weather and hydrological conditions, the amount of seed collected may vary between years and seasons. In spite of this, the method is still widely used all along the coast of China.

Seed collection ground

The best natural seed collection ground is usually peripheral to mussel cultivation areas. Generally

Mussel hatchery

Cultured *Perna viridis*

speaking, natural seed can be collected in any sea area where large numbers of mussels dwell. Several requirements must be met, however, for an area to be a proper seed collection ground:

1. Abundant broodstock resources;
2. Richness of pelagic larvae;
3. Proximity to natural spawning grounds;
4. High water exchange rate with round-about currents;
5. Fertile water and enough plankton for feed;
6. Soft seabed and minimal wind or waves;
7. Low incidence of harmful organisms.

Timing of seed collection

The timing of natural seed collection is determined mostly by the natural spawning period and the pattern of larval development. Differences among species and geographic areas, along with a number of intrinsic and external factors, can cause variations in the rate of larval development and timing of settlement. It is very important to make painstaking investigations into larval dynamics so that the time of spat collection can be precisely forecast. Zeng et al.[10] reported, for example, that green mussels in Dongshan Bay, Fujian province, southern China, reproduce from May to October and settlement occurs from June to November.

In general, settlement occurs 18 to 20 days after spawning. The settlement period of *M. edulis* in northern China is rather long, and there are two peak periods duirng the year: spring spat is collected in May and June, and autumn spat is collected in November and December. Spring spat is more plentiful than autumn spat, grows more rapidly, and is the only spat used for cultivation. Autumn spat grows very slowly until April when the water temperature rises again. The situation is quite different in southern China. In Pingtan, Fujian province, autumn seed of *Mytilus edulis* is collected from October to December and is harvested the next June and July.

Placement of seed collecting instruments must be done at the right time of year. Excessively early placement invites fouling organisms such as barnacles, but overly late placement cannot guarantee that an adequate amount of spat will be collected. According to local farmers in Dalian, Liaoning province, northern China, collection instruments should be placed in the water 20 to 30 days before the peak time of settlement, and no later than late May.

Seed forecasting

The basis for forecasting seeding is the rate of development of natural mussel populations as well as local environmental conditions. For example, salinity is a major factor that may influence mussel spat settlement,[4] and water temperature is also an important factor.[5]

Seed collection instruments

Any object that mussel spat can settle on can be used for seed collection. However, good collection instruments must meet the following criteria: being sustainable, having a relatively large surface area for settlement, containing no contaminants, being widely available and easy to handle.

Coir rope is widely used to collect mussel seed along the China coast. Other materials being used are straw rope, plastic rope, flax rope and rope woven by thin bamboo strips. Even rocks, mollusk shells, broken tiles, bamboo baskets, bamboo curtains, waste iron clods, tree branches, rubber nets and old tires can also be used. Zeng et al.[9] recommended Australian pine trunk, rubber rope and weaved plastic bags filled with foamed

Measuring filtration rate in mussels

plastics as suitable settling apparatus. Whatever the material, the desirable length is 1 to 2 m, and small objects should be strung together.

Seed collection methods

Different methods of seed collection are practiced in different areas. The major ones include raft collection, stone collection and reef collection.

Raft collection. Rafts used for seed collection consist mainly of a raft body (longline ropes), floats, anchor and anchor ropes. The length of the raft is about 80 to 100 m and 200 to 250 seeding ropes are usually hung from each raft.

Another kind of raft that is being used for seed collection is similar to that used for pearl mother cultivation, in which the major structure is tied bamboo or wood. Floating barrels are used as floats, and the whole structure is fixed to the seabed. This type of raft is more difficult to construct, but is easier to handle. Since these rafts are less resistant to waves than other rafts, they are usually placed in deep-water protected bays or inlets.

Stone collection. Stones are used for seed collection of *Perna viridis* in Haifeng, Guangdong province, northern China. Stones weighing 5 to 10 kg are placed on the hard seabed in areas of mussel habitat. The stones must be of a weight and size (cube shape is preferable) so that they are convenient to handle and are not liable to be buried in the sand.

Reef collection. Coastal reefs situated in mussel dwelling areas that are exposed to the air for 3 to 4 hours during low tide can be used for seed collection. Before being used, the reefs should be prepared by removing algae and harmful living organisms. This method is used in Pindtan, Fujian province, southern China, for close island cultivation of *M. crassitesta*.

Management of seed after collection

In Dalian, Northern China, collection of *M. edulis* seed occurs in late May. The spat cannot be seen until late July, and another month and a half is needed for the nursery phase before the spat is gathered together. During this period, management of the collectors is very important.

To estimate the quantity of seed collected on the ropes, a seeding rope is swayed in the water and the spat that drop off are collected and counted under a microscope.

Before the spat can be seen by the naked eye, no cleaning of the collector is permitted even if the seeding ropes are fouled by algae, mud or worms. Since the spat are too small to be well attached to the ropes, any movement of the rope might cause unnecessary drop and loss. The major management work to be done during this period is to take precautions against typhoons. Pendant stones are often used to plummet the main structure of the raft to such a water depth that the force of the typhoon and the huge waves are effectively reduced.

Bivalve culture in Sungo Bay

On-growing

On-growing is the process of culturing the 1- to 2-cm spat to marketable size. Because of the differences in species specifications and environmental conditions, quite a few on-growing methods are used in China, including deep- water raft culture, shallow-water stake culture and seabed sowing.

Deep-water raft culture

Deep-water raft culture is the most widely used method and it is notable for its simple management, high production and effective avoidance of harmful organisms. There are many kinds of rafts being used, such as frame style, net-curtain style, floating-boat style and longline style. The major method used in China is longline style.

Site Selection

Based on experience and the natural mechanisms regulating mussel development, the following points should be taken into consideration when selecting a site for mussel culture:

Currents. Currents have a significant effect on the growth and viability of mussels. Insufficient flow velocity (<10 meters per minute) may cause slow growth in cultivated mussels, while excess velocity might endanger the safety of the raft. Usually, sea areas with current velocities between15 and 25 meters per minute are preferable, and areas with unpredictable current directions or rotating currents should be avoided.

Wind and waves. High winds and waves are potential threats to mussel rafts. While the risk varies seasonally, the north bank faces the wind in summer and the south bank faces the wind in winter. Hence, different cultivation cycles call for the use of different areas of the sea.

Water depth. This is not an isolated factor. In norther China, for example, coastal areas are ice covered during winter and areas should be chosen that have an ice layer < 1 m thick if the depth at low tide is more than 5 m. The thicker the ice layer, the deeper the cultivation area should be. Deep water is proficient for avoiding both flowing ice in winter and extremely high water temperature in summer.

Sea bed. A sand or sand-mud seabed is favourable in that the stakes are easy to place. Stone or gravel seabeds should be avoided in this sense.

Water quality. Unpolluted and fertile sea areas with high secchi depths are favourable for mussel growth.

On-growing instruments

The criteria for choosing materials used in the on-growing of mussels are sustainability, availability, high quality, low cost and low consumption. Longline rafts consist of the main frame, stakes, stake ropes, floats and hanging ropes.

Main frame (longline rope, floating rope). Two types of materials can be used: industrial products such as polyethylene and plastics, with an effective length of 30 to 60 m, a thickness of 9 to 14 mm, and a service life of 4 to 6 years; and agricultural material such as straw rope, bamboo-strip rope, etc., with an effective length of 50 to 60 m, thickness of 50 to 60 mm and a service life of 6 or 7 years.

Anchor. There are also two kinds of anchors being used. One is wooden, made from tree trunks and with a service life of 2 to 3 years. The other is cement, made of iron (or steel) cement and sand, and has a service life of 6 to 7 years.

Anchor rope. Anchor ropes are mostly made from polyethylene or plastics and have the same or slightly less thickness as the longline rope. Total length varies according to the water depth, and is usually twice the water depth of the spot. Longer anchor ropes are beneficial to the steadiness of the raft; a short anchor rope is less resilient and anchors are liable to be pulled out by waves.

Floats. Glass balls with covers are used as floats. Diameter of the balls are 30 to 32 cm and the buoyancy is about 28 kg.

Hanging rope. The hanging ropes are mostly polyethylene or plastic with a thickness of 4 to 5 mm, a length 60 to 100 cm, and a service life of 2 to 3 years.

Seeding rope. The seeding rope can be anything that mussel spat can settle on. Depending on the availability, coir rope, grass rope, bamboo-strip rope and old tires can all be used.

Manufacture of on-growing instruments

Raft arrangement. Productivity can be increased by increasing the distance between the mussel rafts. Raft distance is generally 8 to 10 m, with a line distance of 20 to 30 m, and a column distance of 40 to 50 m. The rafts are usually arranged in railing style, diamond style or ladder style. Diamond style arrangements are effective in guaranteeing water exchange and that sufficent feed organisms reach the mussels when large amounts of rafts are placed in an area.

Spat separation and on-growing. Separation of mussel spat should be done as early as possible.

Spat transport. Dry transport of the spat can

Mussel rope made of 2 or 3 twisted strips of worn tires or mixed polyethylene and palm fibers.

be used over shorter distances, but shading and water spraying are needed to maintain high humidity and to maximize survival. Long-distance transport requires the use of boats with flow-through holding tanks or refrigeration systems.

Spat separation. There are two substantial growing periods during the life cycle of *Mytilus edulis* each year. In Dalian, northern China, the growth periods are May and June in the spring and September and October in the autumn. At these times the water temperature is between 14° and 23°C, which is optimal for mussel growth, and a growth rate of 10 mm per month can be achieved. Early separation of spat should be done before the end of August, so that juvenile mussels can take advantage of their fast-growing autumn period. This ensures that a large proportion of the mussels reach marketable size by the spring. This is the profitable "two-crop" way of mussel cultivation. Methods for spat separation include: rope-binding, removing, sandwich and wrapping.

Rope-binding. This process includes thin-rope-binding and thick-rope-binding. In thin-rope-binding, a segment of the seeding rope is bound onto the on-growing rope, so that the proper density of mussels can be achieved. In thick-rope-binding, the on-growing rope is wound onto the seeding rope, so that the spat may be later transferred and diluted.

Removing. In the thick-rope-binding method, small spat is removed from the rope; the larger spat are retained for on-growing and the seeding rope is used as an on-growing rope.

Sandwiching. The spat are peeled in clumps from the seeding rope and are sandwiched in small bunches into the rope crevices.

Wrapping. Seven steps are involved this method, but the major processes can be summed up as: the pealed-off and sieved spat are wrapped onto the on-growing rope with nets. The spat are well-distributed and are wrapped in the appropriate density.

Shallow water stake-culture

Wooden stakes, stone slabs and frames are set up near or 1 to 2 m below the low tide line, and juvenile mussels are wrapped onto the stakes or hung from the frames for on-growing. This culture method is notable for its resistance to wind.

Seabed sowing (bottom culture)

Rocks and oyster shells, used as settlement instruments, are evenly scattered onto a hard seabed of gravel or rocks. Mussel spat are evenly sowed during low tide, so that they can settle and grow properly. Another approach is to throw the spat-settled instruments on a suitable seabed for on-growing. This method is notable for its ease of handling, low cost, and resistance to typhoons, high temperatures and freezing. This method is suitable when mussels have to be cultivated for 2 years or longer to reach market size. The shortcomings of this method are the slow growth rate of the mussels, the lower production, and the vulnerability of the mussels to harmful organisms.

Culture periods and harvest

The length of the culture period is affected by the culture method, the specifications of the species, and the desirable marketing size. The normal harvest size for mussels is 6 to 8 cm, with an individual weight of 15 to 20 g. The usual cultivation time for raft-cultured *Mytilus edulis* in northern China, for example, is 12 to 18 months but it can be shortened to 4 to 6 months if appropriate separation and hanging methods are used. Seabed-sown *Perna viridis* in southern China can reach market size in 2 to 3 years, but a shorter rearing period was reported by Zhang et al.[10] *M. coruscus* settled on island reefs normally have a cultivation pe-

Polyculture of blue crabs and mussels

riod of 2 years, but they can be be harvested within 1.5 to 2 years under raft-culture conditions.

Polyculture

Polyculture of blue crabs and mussels

In the polyculture of mussels and crabs, longline ropes of the two species are placed so that they alternate. A normal density of mussels is used and one crab is cultivated in each layer of the lantern net. Forty to 60 lantern nets are hung on one longline rope. The crabs are fed 2 to 3 times per week with mussels, clams and salted fish. Crabs can grow from an initial size of 2 to 5 cm to a marketable size of 200 g within 4 to 5 months. Several advantages highlight this type of polyculture: the culturing density of the mussels is reduced, but the economic benefit is increaed; on-growing mussels neighbouring the crabs can be used as feed for the crabs, which reduces labour costs and converts low-value animals to high-value ones.

Polyculture of blue mussels and sea cucumbers

Mussel ropes are encased with nets, in which 6 to 10 sea cucumbers are cultivated.[6] Sea cucumbers are fed every week with smashed seaweeds during their fast growing season in April-May and October-November. The sea cucumbers can reach market size within one year and the economic benefit is greatly improved.

Polyculture of mussels and kelp

In this type of polyculture, mussels are hung vertically from the rafts and kelp is hung horizontally. The mussels and kelp are cultured alternately and the density varies with the carrying capacity of the culture site.[8]

Problems and Strategies

Problems

A. Because the high density at which mussels are being cultured exceeds carrying capacity, culture times are prolonged and meat yields per shell are decreased.

B. Since mussels command a lower market price than most other aquaculture species in China and because of their high reproductive capacity, mussels sometimes cause trouble in the culture of other species because they foul the nets.
  - Fouling on culture facilities such as floats can increase the cost, as more floats are required.
  - Mussels can block the mesh of scallop lantern nets and fish cages, so that the growth of the cultured animals is reduced.
  - Mussels compete with other filter-feeding animals for food organisms.

C. Mussel culture can influence and change the marine ecosystems of coastal zone waters:
  - Sediment produced by cultured mussels over a long period may influence the stability of coastal ecosystems;
  - Accumulation of faeces can change the sea bed texture and then change the benthic ecosystem;
  - Sediment from mussel culture rafts can be easily agitated by strong wind and currents, and the rich nutrients recycled into the water column can cause eutrophication and red tides.

Strategies

The study of carrying capacity of sea areas for shellfish cultivation can provide scientific guidelines which the mussel aquaculture industry in China should abide by.

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The Netherlands:
The Cradle for Mussel Farming on the Bottom

Jan Bol

Harvesting on public mussel beds in the 18th century led to overfishing. Mussel culture began in the 1870s in Zeeland waters and this increased mussel production and expanded the market. The Zeeland area is close to the Belgian and French markets, which are large consumers of mussels. In 1917 an unidentified disease destroyed the mussel culture industry and in 1950 the parasite *Mytilicola intestinalis* caused high mortality in mussels in the Zeeland areas. After that, farmers began growing mussels in the Waddenzee. Larger boats, better equipment and more rapid growth rates have increased mussel production and product quality. Scientific research has provided information needed for site selection, including current speed, grain size of the sand, salinity, turbidity, etc. Improvements in mechanization, transport and refrigeration have given the mussel traders more opportunities to extend their markets.

History

Before mussels were cultured, there was a mussel fishery in the southern part of the Netherlands that exploited wild beds. But by the mid 1800s, mussels on these beds were becoming rare because of overfishing.

In 1825, there was already a Committee for Fishery on the Zeeland waters. The committee developed regulations and issued fishing permits. In 1870, the Committee and the government decided to grant public grounds in concession, an important first step for mussel culture. The main fishing area for mussel seed was the Zuiderzee. In 1932, the Zuiderzee was closed from the Waddenzee by a large dyke that was 30 km long. After that the quantity of mussel seed obtained from the Zuiderzee varied from year to year and when it was low, seed was obtained from the Waddenzee, from England, and from the pileworks along the Belgian and Dutch shoreline. Seed collected from the shoreline was of high quality and provided a good return (volume increase).

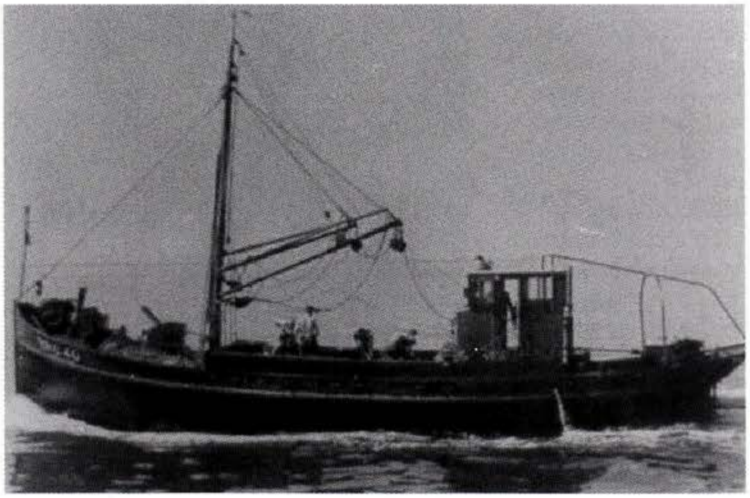
Over the years, more and more lots were used to culture mussels and the lots were acquired, not only concession, but also by leasing grounds. The export of mussels for human consumption was mainly to Belgium, France and England and the exported mussels were transported by boat.

The mussel farming techniques used originally in the Zeeland area were slightly different than the techniques being used nowadays in the Waddenzee. For example:

a) Seed were spread on sheltered exposed lots in May and June when the seed was 10 months old;

b) After summer growth and overwintering, the seed were transplanted the next spring to a deeper lot until they were half grown;

c) The following year, the seed were transplanted a



Manual unloading of mussels over the railing

Figure 1. Map of the Netherlands showing the mussel farming areas

second time and grown until they reach consumption size.

The growth of the mussels is slower in Zeeland, but the returns from mussel culture were greater than they are nowadays — five to ten times greater, and more, was no exception. But in 1917, disaster struck when heavy mortality destroyed the mussel culture industry. To this day, the cause of that mortality is not known.

During this period, there was already some mussel fishing and farming in the Waddenzee. During World War I there was in our village of Yerseke a lot of processing of mussels ("house cooking"). During World War II, particularly from 1943 until 1945, there was a drop in mussel production (see the supply figures). The largest part of the production went to the 11 cooking factories in our village and the mussels were used as food during the German Occupation. Currently, there are only 3 cooking factories, as the main market is for fresh product. Before 1950, the production from the wild mussel beds in the Waddenzee went mainly to the duck farmers in the center of Holland and to England for human consumption. Half-grown mussels and seed went to the culture lots in Zeeland.

In August 1949, the parasite *Mytilicola intestinalis* was discovered in the Zeeland area. This parasite caused the condition of the mussels to deteriorate and later on there was high mortality. Mussels in other areas also became infected, because mussels were transplanted from one area to another. The infected mussel seed had originally been fished in the German Waddenzee, close to the Dutch border, but at the time no one knew that the mussels were infected by the parasite. The influence of the parasite on mussel production was not noticed for 4 years. After this disaster, a group of 10 farmers began farming mussels in the eastern Waddenzee in 1950. In 1951 and 1952, all the farmers had begun farming in the western Wadden- zee, but they developed the industry slowly, one step at a time. Since that time, there have been two farming areas in the Netherlands: Zeeland in the south and the Waddenzee in the north.

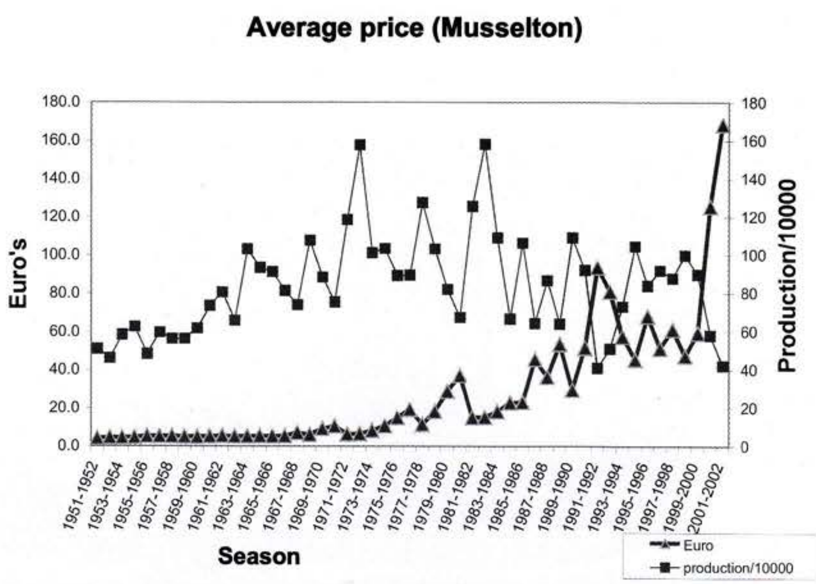


Figure 2. Average price of mussels per tonne (in euros) and total mussel production from 1951 until 2002. Data demonstrate the influence of the mussel auction that opened in 1967 and the influence of supply and demand on the price of mussels.

General Information

Conditions for the

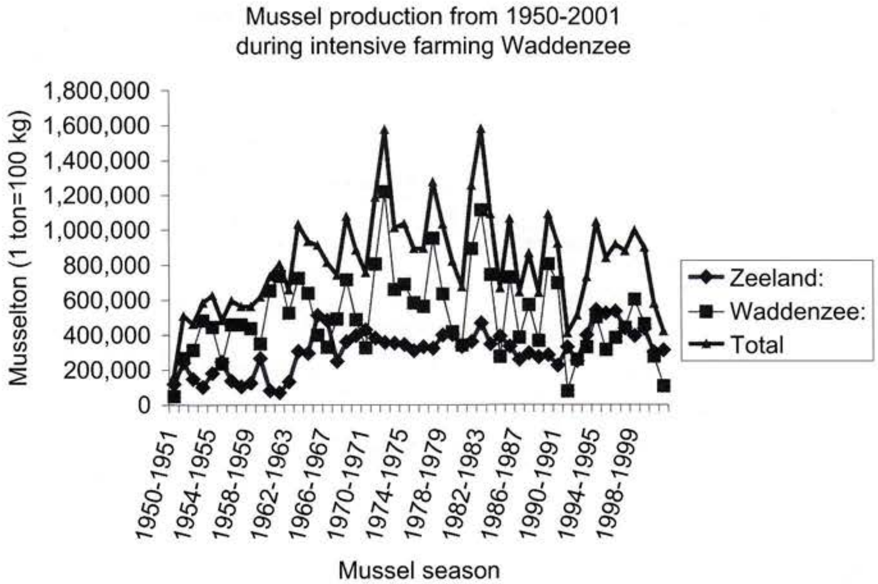


Figure 3. Mussel production from 1950 to 2001 during intensive farming in the Waddenzee. Production in Zeeland and the Waddenzee and total production in musselton (1 ton is 1000 kilograms).

bottom culture of mussels are favorable in the Zeeland area, as well in the Waddenzee. We are lucky that in the Netherlands all the wastewater is treated before it goes into the sea and we, therefore, have had no problem with pollution on our farming lots. Sometimes we have a short period of diarrhetic shellfish poison (DSP), mainly in the Waddenzee. In the Zeeland area we can have problems with *Pheocystis*. The Deltaplan in the south created a storm surge barrier which reduced the current speed by 30%. That made it possible to create mussel lots in places where previously the current speed was too high. But in some places there is more sedimentation than there used to be.

The newest mussel vessel

The mussel farming industry in Germany is very similar to that in the Netherlands. The Germans started growing mussels before World War II in Sleeswijk Holstein and Nieder Saksen, which are part of the German Waddenzee. The German farmers began with assistance from the people of my village, Yerseke. Their farming efforts were scaled up during the War.

There are now large mussel farms in Germany owned by a

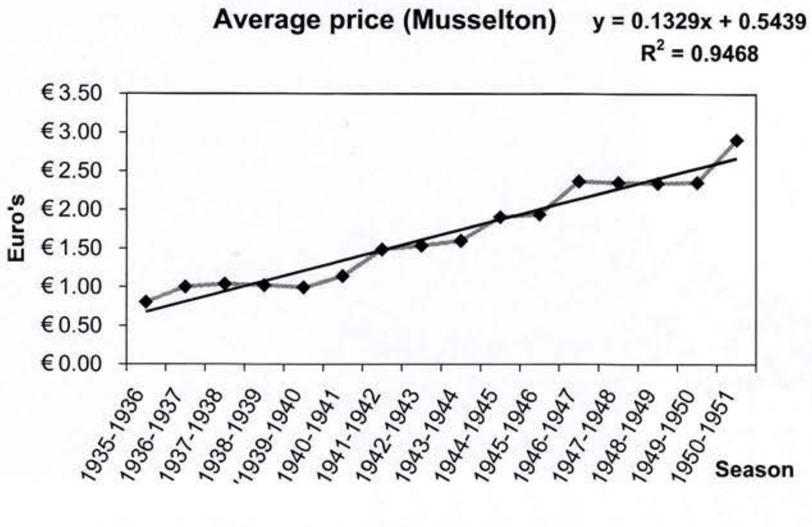


Figure 4. Average price of mussels per metric ton.

Dutchman. Most of the German production goes to Dutch traders, as the Netherlands is the European center for trading in mussels. The only mussel auction in the world is located in Yerseke. The Netherlands imports mussels from England, Ireland, Denmark and Norway. The mussel farming industries in Ireland, Denmark and Norway are expanding rapidly.

Mussel farmers in the Netherlands were first organized in 1935. At the time there were about 120 farmers; now there are 70. Some mussel farmers only grow mussels, but other farmers are also traders. Many of the farms have been taken over by the traders, so there is less dependence on the mussel auction.

The total area of mussel farming ground is roughly 4000 ha in the Waddenzee and 2000 ha in Zeeland. The number of lots in the Waddenzee is 480 and the average size is 8 ha. There are 300 lots in Zeeland, with an average size of 7.5 ha. Almost all the ground in the Waddenzee that is suitable for mussel farming is in production. The shrimp fishermen oppose the issuing of ground to mussel farmers.

Most of the mussel lots are 200 m wide and slope to the channel. The length of the lots varies between localities. The lots are marked using oak poles and deeper lots are marked with buoys. Prior to 1920, the mussel farmers used wooden sail boats, but in the 1920s they began using steel boats with motors. Now the largest ships are 45 m long, 10 m wide and have 1200 hp engines. The draught of these ships is 0.85 m when they are empty and 1.4 m when they are loaded. The loading capacity is 200 tonnes of mussels and the ships are equipped with 4 dredges, each 2 m wide, and a hydraulic or pneumatic 8-drum winch for hauling and emptying the dredges. The maximum fishing capacity under favorable circumstances is 40 tonnes/hour.

Over the years, the technology for unloading the boats has changed from manual unloading of mussels over the railing, to the use of "seed tubes" and "conveyor belts", and finally to a system that uses water. Water is pumped into the hold until the ship is higher than the external seawater level. This provides pressure enough to wash the mussels out of the boat via a gate in the side of the ship. Everything is controlled from the wheelhouse. There are usually 3 or 4 crew on the ships, depending on the size of the farm. The current cost of building a ship for mussel farming is approximately 3

Harvesting mussels from the bottom

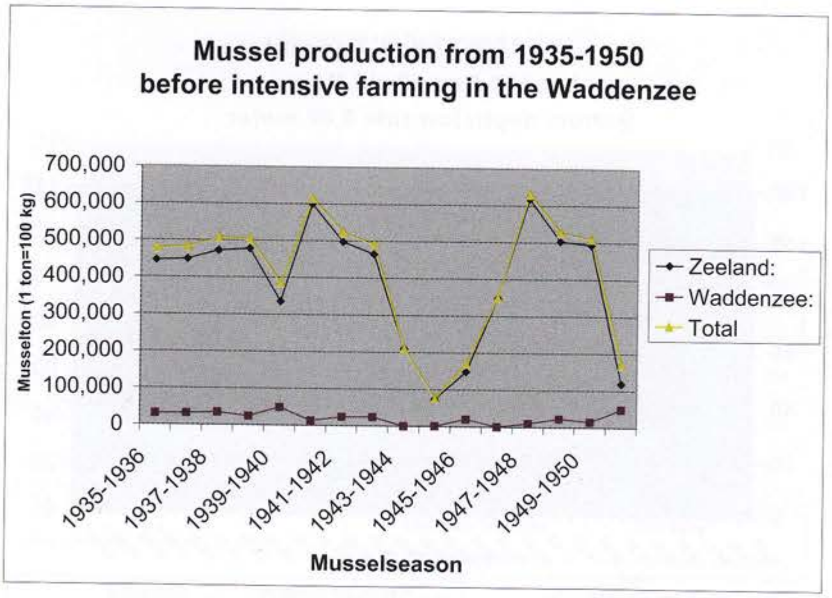


Figure 5. Mussel production from 1935 to 1950 before intensive farming began in the Waddenzee. The main production was in the Zeeland area. The drop in production in 1940/41 occurred at the beginning of the German Occupation. In 1944/45 the decrease was due to the liberation by the Canadians and also because there was no production in the Waddenzee. The final drop in production was due to mortality caused by the parasite *Mytilicola intestinalis.*

to 3.5 million euros. The price the farmers receive for mussels is increasing and some farmers can make 2 to 2.7 million euros in one season. That is the reason they can build and equip very good ships.

Mussel Farming in the Waddenzee

In the spring of 1950, a select group of 10 mussel farmers started farming in the eastern Waddenzee. They had good results and in 1951 they started farming mussels in the western Waddenzee. They stated slowly because they had little knowledge about farming in the western Waddenzee. During World War I, some mussel farmers from Zeeland started farming in the Waddenzee and some had poor results, so their relatives were reluctant to try again.

Compared with the Zeeland area, the Waddenzee is rougher, less sheltered, and shallower. The current

Dredge ready for fishing

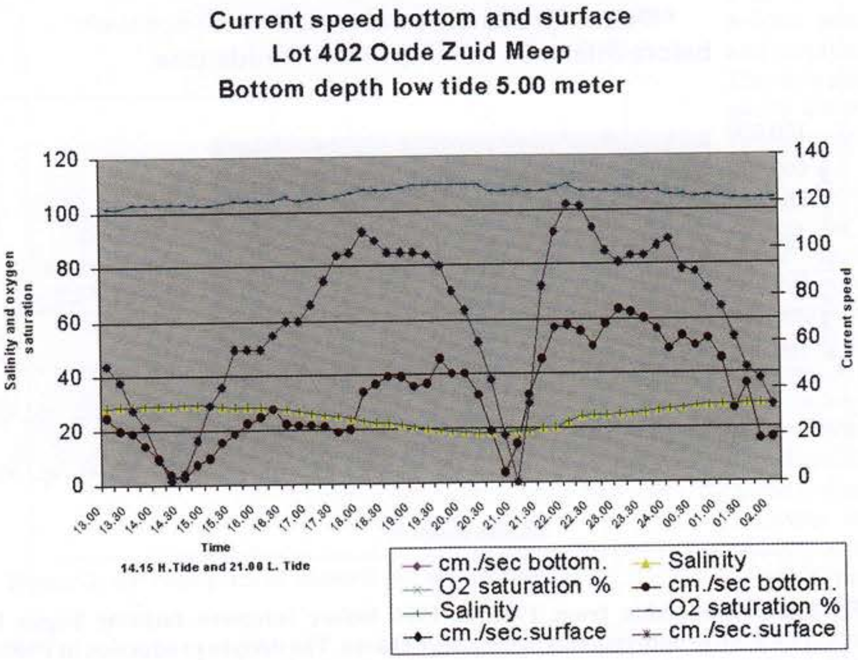


Figure 6. Comparison of current speed between the bottom and surface in cm/second on Lot 402 Oude Zuid Meep. Bottom depth at low tide is 5 meters. Salinity and oxygen saturation measurements were taken every 15 minutes. The strongest increase in speed begins at low tide and reaches the maximum speed in 1 hour. The ebb cycle is more equable. This is one of the characteristics of most of the lots in the Waddenzee. Recording was in wintertime and therefore the salinity in the Waddenzee can fluctuate under discharge from Lake Ijssel. Oxygen is normal.

Preparation of mussels for sampling

speed is higher, particularly through the narrow channels. During storms, there is enormous transport of sand and mud. The salinity is lower because of the influence of fresh water from Lake Ijssel. In the wintertime, the Waddenzee is colder than the Zeeland area and there is very rapid ice formation. Moving ice can destroy all the mussels on a shallow lot. The growth rate of the mussels in the Waddenzee is normally higher than in Zeeland.

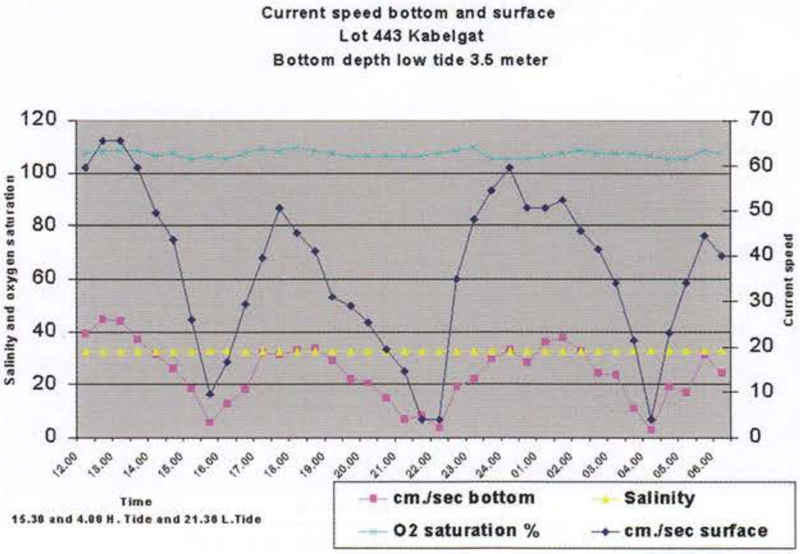


Figure 7. Current speed at the bottom and surface of Lot 443 Kabelgat. Bottom depth at low tide is 3.5 meters. Recording was in the summertime. Salinity was very stable and oxygen is also normal. From low tide, it takes 2.5 hours to reach the maximum speed, but there is a large difference in current speed between the bottom and the surface.

Some places where they began farming were overcrowded with starfish and it was not possible to continue. The number of eider ducks increased as the number of mussel farms expanded. In wintertime, there can be 200,000 to 300,000 ducks, each of which can eat 2 to 3 kilograms a day (60% mussels, 20% crabs, 20% starfish).

In general, when there is a good seed supply, a mild winter and no storms, the Waddenzee can produce a lot of mussels. From the 1960s through the 1980s, the proportion of mussel production coming from the Waddenzee and Zeeland was 70% and 30%, respectively. During that time, there was no restriction on collecting seed and the lots were optimally utilized.

All the mussels grown in the Waddenzee are transported by boat through inland waters (17 to18 hour trip) or via the Noordze (13 to 14 hour trip) to the auction.

Mussel Production, Organization and Sale

The average annual production of Dutch mussel farmers is 80,000 to 100,000 tonnes, depending on the

Mussels in the hold of the ship

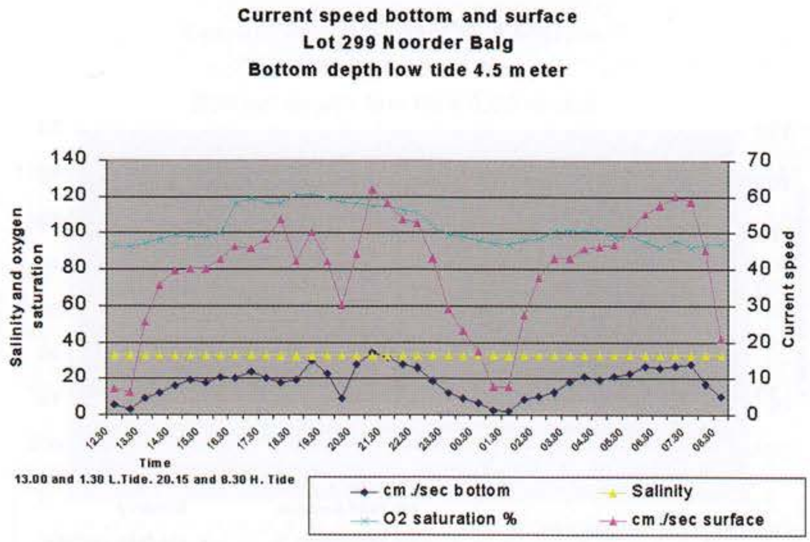


Figure 8. Current speed on the bottom and surface of Lot 299 Noorder Balg. Bottom depth low tide is 4.5 meters. Recording was in summertime. Salinity was very stable. But the recording of oxygen showed increased consumption at night.

quantity of seed and the return. Negative influences on mussel production include storms and extreme current speed. Between 1985 and 1991, mussel production from the Waddenzee fluctuated. Between Christmas 1991 and early January 1992, most of the mussels were washed away by the extreme current speed in springtide. The maximum production in the Waddenzee and Zeeland occurred in 1982/3, with 111,000 and 47,000 tonnes being produced, respectively. The overproduction in that season was 42,000 tonnes. In the late 1960s and during the 1970s, there were also years of overproduction because of the huge amounts of seed available. For these mussels there was a fixed bottom price. The average yield over the past 5 years has been 71,800 tonnes and the average value has been 920 euros/tonne. In the Waddenzee, the time required to grow out mussels from seed to consumption is about 2 years, sometimes less.

Prior to 1935 there were various attempts at organizing the mussel farmers, but they were not viable. Each farmer sold his product free. Most of the farmers transported their mussels by boat to Belgium and

Evaluating the 25-kg samples of mussels

View over the Oosterschelde from a dyke

northern France, but some farmers trucked their mussels. Others sold to a dealer. During this time, some traders started to clean their mussels in sheds before marketing them, using scissors to remove the byssal threads and separate the mussels. That was a friendly system compared to that used today, but it was very labor intensive.

The government instituted supply management measures during the economic crisis of the 1930s. They started a "Mussel Office belonging to the Commodity Board for Fish and Fishproducts". The office organized the entire mussel supply. Each year, before the season started, the office established a fixed price based on the size of the mussels. There were three grades (A, B and C). Before the mussel office was established, each farmer had a standard capacity figure, based on surveys done on the lots. Farmers with a large stock of mussels also get a high capacity figure. The farmers received their orders from the mussel office to supply the dealers or traders. For each farmer the deliveries went in equal percentages. Also the mussel office regulated the export of mussels and this was also based on quotas. The standard capacity figures were different for each farmer and ranged from 1000 tonnes for the largest farmer to 15 tonnes for the smallest. The production in 1935/36 was 44,500 tonnes from the Zeeland area and 3600 tonnes from the wild mussel beds in the Waddenzee. This system of using capacity figures was used until 1967 (a very long time for a measure instituted during a crisis). Since 1950, in the Waddenzee, the quality of the mussels has been excellent and the yield has been high. However, quality was not a factor at that time in determining the price paid. That brought a lot of displeasure to the farmers. In

Mussel auction at Yerseke

1967 the farmers began an auction and the system of using capacity figures became obsolete.

Today all the mussels produced for consumption go through the auction at Yerseke. Auction workers take a 2.5 kg sample from each hold and from that they define the percentage waste, fixed length and width categories, percentage meat weight after cooking, and the number of mussels in a 2.5-kg net. All these figures provide an indication of the quality of the mussels. The auction uses an electronic bidding system, with every buyer placing their bids using a laptop computer. The price paid depends on the quality of the mussels as well as supply and demand. After the auction most of the mussels are taken to the rewatering area, which are lots in the Basin of the Oosterschelde, 250 ha in the front of Yerseke. The proximity to both the rewatering areas and the main markets in Belguim and France is the reason mussel trading is concentrated in Yerseke. The consumption of Dutch mussels in Belgium, France and the domestic market is respectively: 60%, 32% and 8%. Some loadings go directly into the desanding containers on the shore. Because of the increasing production and transport possibilities, the market is also increasing.

Fishing from the Public Beds

Spatfall occurs in June and July, and fishing begins in October and continues for 1 or 2 days a week for several weeks. To fish on the public beds, farmers must obtain an exemption from the Department of Fishery. The rest of the year, the public beds are closed. The quantity of spat that farmers are allowed to remove depends on how much spat there is on the public beds, and that is determined from a survey.

In the past, the entire Waddenzee was available for fishing spat during the exemption period, but currently, a large part of the littoral Waddenzee, mainly the eastern part, is closed to mussel and cockle fishing. The purpose of the closure was to create a food reserve for eider ducks and oyster catchers.

In the western Waddenzee, the main fishing area for mussel spat is sublittoral. Fishing begins in the most risky areas to avoid having the seed being carried away by wind or eaten by starfish. The different fishery committees set the quantity of seed that can be taken and the allowable fishing days. The main fishing period occurs in May and is spread over 4 to 5 weeks, with every week being allotted a fixed share of the total amount of seed that can be harvested.

For the past 10 years, every farmer has had a spat quota or share of spat. The percentage of the total alloted to each farmer is based on the farmer's yearly average sales over the past 25 years. For instance, if the stock is 40,000 tonnes and a farmer's share is 2%, then his quota is 800 tonnes. In the past, when there wasn't a quota, it was a nerve-wracking period for the farmer.

Site Selection

The conditions for mussel farming depend on natural and hydrographic circumstances. Important factors are: location, depth, current speed, bottom structure, sand ridges, grain size of the sand, water flow, salinity, and turbidity.

Location

Sites should be well protected, behind a dyke or shoal, and sheltered against the prevailing wind. In protected areas, water depths can be shallower.

Measuring the length of the mussels

Water depth

The depth requirement varies with current speed and the degree of protection. If is preferable that the lots not be deeper than 10 m, or the mussels become weaker and have a thinner shell. In deeper water and closer to the mouth of the bay or entrance to the channel, there is usually more predation by starfish.

Current speed

Current speed of the water can also be influential. The speed at the surface is always higher than at the seabed and the deeper the water, the greater the difference.

Bottom structure

Bottom structure is an important criteria. A rough bottom indicates that the water has a high current speed and there is a lot of turbulence.

The most favorable bottom is smooth, without sand ridges. The presence of sand ridges can be detected using an echo sounder which records the bottom structure as the ship is sailing very slowly. Another option to detect sand ridges is to tow a dredge. If the dredge jumps too much, it indicates the presence of a hard sandy bottom with sand ridges. In the past, farmers checked the condition of the bottom using a long pole and that method is still sometimes used.

Composition of the sand

Another important criteria is the composition of the sand. This can be checked by slowing down the vessel while dredging, until the vessel is stopped. If the dredge gets stuck, the probability of successfully farming the site is low as usually this indicates the presence of quicksand and an unstable bottom. Also, they should observe whether there is bottom flora and/or fauna (e.g., a single mussel or mussel shells, oyster shells, anenome, whelks or both). The presence of many cockle shells in the dredge can be an indicator of high current speed and therefore grain size larger than 300 microns. When you start farming on a lot with a grain size of 150 microns or larger, there is greater risk that the mussels will be carried away. It is preferable to not have too much slope, otherwise it is difficult to dredge.

Water flow rate

You need a good water flow rate every tide with salinity of 25 ppt or higher. If the salinity is lower, it may not be a problem for the mussels. Under normal conditons, the turbidity in the Waddenzee is between 20 and 40 mg/L of suspended solids. In the Zeeland area it is 5 to 20 mg/L.

Vessel with containers of mussels

Issuing and Classification of Lots

The Department of Fishery regulates the issuing of lots and every lot is classified based on past farming yields. The different classifications are: 1A = 10% of the lots, 1B = 30%, 1C = 20%, 2 = 20%, 3 = 20%.

Generally, lots classified 1A and 1B are used to produce mussels for consumption. Lots classified as IC are used to grow both consumption mussels and half-grown mussels. Lots classed 2 and 3 are used to grow half-grown mussels and seed.

Special note: It is not possible in the Netherlands to start a mussel farm. When someone would like to become a farmer, they have to buy an exisitng farm. However, most of the farms are family farms and pass from father to son.

Processing, Packing and Transport

When the mussels are dredged from the rewatering lots they go to the shore for desanding. The desanding takes place with clean running water and sometimes ultraviolet (UV) sterilization is used.

After desanding for 6 to 10 hours, the mussels go through the machinery that washes, debysses and packs the mussels. Nowadays, the mussels are packed in leak-free vacuum trays as well as plastic bags. The latest development is the pre-cooling of the mussels in 4°C water prior to packaging.

The mussels are sorted by size and MAP (modified atmosphere packing) is used, which extends the shelf life. The specifications of the packing system are kept secret, but I know that some packers use water, nitrogen and other things. The different size packs in MAP are 1 kg, 2 kg, and 10 kg. Also a 15-kg jute sack is used. The number of mussels in a 1-kg package is: Standard 80+, Extra 70+, Super 60-70, Imperial 49-59, Jumbo 43-48, and Goldbrand 35-42. The whole operation is controlled by the government based on EU regulations.

New Developments

In some areas of Zeeland mussels are cultured on ropes. However, rope culture represents only 5% of the total mussel production. The farming area in Zeeland used for rope culture is well sheltered. The benefit of this approach is that mussels with a high meat yield can be produced with no sand or mud before the season for bottom-cultured mussels begins. Because of this, rope cultured mussels command a high price. Since 2001, one trader has been using new machinery to remove mussels with barnacles. The technology comes from the potato industry and uses an electronic eye.

Another new activity is the treatment of waste water from the plants. Because 7 traders are located close together, each one takes seawater from the same channel. The effluent water from the desanding containers in each plant goes back into the channel again. This effluent water can influence the quality of the intake water and sometimes there is a problem with bacterial pollution. To solve this problem they use UV sterilization. The water intake pipe is now located 1500 m from the plants and brings good quality seawater to the plants through a pipeline under the seabed. The cost to install this water system was 14 million euros. The traders received a 50% subsidy from the European Commission and the remaining 50% was paid by the traders and farmers. The farmer's share was paid through a levy on mussels arriving at the auction.

At the moment there is a trial in the Waddenzee being conducted in the hold of a ship using frames with holes in different floors, where they grow mussels from seed. Researchers are expecting a very high growth rate and hope that 1-year-old spat will grow to consumption size in 6 months. Perhaps a utopia? It is a feasibility study. The next step is to use a pontoon to scale it up and test if it is profitable. They also expect less mortality of the spat. All the questions are not yet resolved, including what will happen in winter time with a lot of moving ice, what are the total costs, etc.

In the Netherlands there is a tendency for mussel farming on the bottom to become more and more difficult in relation to nature conservation. Be attentive to that in your own situation!

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Canadian Mussel Aquaculture: An industry with Room to Grow

Crystal McDonald, Richard Gallant and Cyr Couturier

The Canadian mussel aquaculture industry has become well established over the past two decades. Canadian production has just reached 25,000 tonnes per year, less than 2% of global production. Although the industry is still comparatively small it is a significant economic generator for rural Canada, with annual growth rates exceeding 15% over the past decade. Commercial mussel production occurs on both the Atlantic and Pacific coasts (in six provinces), in approved growing waters of the highest quality. Opportunity exists for this sector of the aquaculture industry to grow even further if environmental, regulatory and social conditions are favorable. An overview of the industry, including historical perspective, grow-out technologies, processing activities and markets, production statistics, as well as challenges and successes, are presented. Also a glimpse of the future Canadian mussel industry and the potential for growth and limiting factors are explored.

Canadian Mussel Industry Overview

The cultivation of mussels in North America began in the 1960s and 1970s along the Atlantic Coast with industry pioneers in Canada (Nova Scotia and Prince Edward Island) and the United States (Maine) experimenting with raft culture and other technologies. In the late 1970s, the Prince Edward Island (PEI) industry set aside this method of culturing and instead chose to develop the longline system that is still utilized to this day.[1]

The first commercial production of mussels in Canada occurred in the late 1970s on PEI. Several other Canadian provinces have adopted similar culture practices, although some raft culture still occurs in British Columbia.

Canada has ample coastline for the mussel industry to flourish. While the topography may vary from one province to the next, there are similarities, including the presence of shorefast ice during the winter months, except in British Columbia and the south coast of Newfoundland. The abundance of large, pristine, sheltered bays and inlets around the Canadian coastline offers great potential for future expansion of the industry and development of sustainable economic engines for rural communities.

Canadian mussel production in 1999 was a little over 17,000 tonnes. In 2001 the total annual produc-

Typical mussel barge, approximately 20 m in length

tion jumped to 21,666 tonnes with PEI producing 17,506 tonnes, Nova Scotia (NS) producing 1,619 tonnes, Newfoundland (NL) producing 1,452 tonnes, New Brunswick (NB) producing 750 tonnes and Québec (QC) producing 339 tonnes. The landed, farm-gate value for the 2001 production exceeded $30 million CDN.[2]

While Statistics Canada did not report mussel landings in British Columbia (BC) in 2000, the BC Shellfish Growers Association reported 14 tonnes with a farm-gate value of $62,000 for that period.[3]

With consistent growth over the past decade, PEI has become the North American leader in mussel culture, with production doubling from 1995 to 2000. In fact, PEI's production for 2000 had a landed value of $22 million, representing 82 per cent of the Canadian total for that period.[2]

Continuous mussel sock being deployed experimentally in some areas of Atlantic Canada

In 1992, Canadian mussels accounted for approximately 20 per cent of the North American mussel market, including fresh and frozen. By 1998 this percentage had increased to 42 per cent and since that time has grown to an estimated 50 per cent of the North American fresh and frozen mussel market.

Part of the industry's success over the years is its capability to supply the market year round. This ability is in large part due to the development of winter harvesting technologies. A large percentage of Canadian production is exported in the whole fresh form, although value-added products (e.g., frozen and marinated) are starting to gain a good reputation in the market as well.

Suspension floats (40 cm diameter) and concrete anchors employed in single longline systems

Currently there are approximately 10,000 hectares of aquatic resource approved for mussel aquaculture activity across Canada, with approximately 50 per cent of that area being utilized. The benefits of a successful mussel industry to Canadian rural communities and economies are multiple. Rural communities are able to supply much of the workforce (2,000 to 2,500) that is required to culture and process these high-quality products. While some of the jobs are seasonal, there are also numerous permanent jobs (full time and part time) with some of these requiring a technically-trained staff due to the industry's continuous evolution.

Cultivating Mussels

There are three species of mussel cultivated in Canada, although production is predominantly *Mytilus edulis*. The mussels follow similar collection and grow-out technologies in most provinces with the exception of British Columbia where seed is produced in the hatchery and some raft culture still occurs.

The development of the single, submersible longline technology utilized by Atlantic Canada was deemed a critical step in the development of the mussel culture industry. The technology is less susceptible to the elements (ice and wind) and requires a minimal initial investment compared to raft technology. The longline system consists of a buoyed backline from which mesh sleeves (better known as socks) or seed collectors are hung. While traditionally the backline has been anchored at each end with concrete weights, over the last five years the industry has moved towards alternate anchor systems such as screw-in anchor or rock-bolt technology.

Once the mussel seed has been collected, declumped and graded (5 to 10 months after settlement) it is ready to be deployed into pre-cut socks made of poly-blend mesh materials. There is a mixture of woven and extruded socking material available, depending on the depth of the site and the preference of the farmer. These socks are then tied to the long-line structures in the water. Several provinces with sufficient water depths are currently examining the possibility of using New Zealand or Spanish-style continuous socking techniques as a more viable option for growout compared to precut sock lengths.

While some growers purchase their seed from other individuals, many supply their own. Seed is collected on fuzzy ropes (single or continuous) that are suspended in the water column along a backline when the mussels are spawning. Careful monitoring is undertaken by farmers, with technical support from various agencies, to ensure the collectors are deployed at the

Harvesting single drops in winter (A. Struthers photo)

Ice up to 90 cm thick provides a stable harvest platform (A. Struthers photo)

right time to optimize collection and avoid fouling and predators. The seed is then taken to shore where it is put through a declumper and graded prior to socking at final densities appropriate to the site, typically ranging from 500 to 1000 mussels per meter when deployed. Mussels spawn in Canadian waters at various times depending on site specific conditions: Prince Edward Island in late May to early June, Nova Scotia in early June to early July, and Newfoundland from early June to early September.

Growers will hang out their socks and then depending on the site and husbandry practices, they may allow the mussels to periodically touch the substrate so that crabs can clean the biofouling that has accumulated. This process works only in areas with shallow depths, and is not practicable in most mussel growing areas. During final growout, some growers keep their lines buoyed up to the surface while others maintain the crop at least a meter below the surface.

Mussel backline with continuous droppers

Depending on the area, the size of the seed socked and the abundance of food in the water column, harvesting will usually begin 12 to 18 months after the socks are deployed on the longlines. Most growers have predetermined harvest schedules and, with the advent of winter harvesting technology, quality Canadian mussels are able to reach the market year round. As with most commercial-scale aquaculture operations, the Canadian industry is becoming increasingly mechanized in efforts to eliminate some of the costs and ensure a high quality and safe product for the consumer.

Front view of mussel harvesting barge

Winter harvest typically begins in January when the ice is 30 cm thick. However, the changing climate conditions have caused growers to continually adapt their techniques so that they can access their mussels through thinner ice. The mussel industry is innovative and the weather and the elements (e.g., icebergs, heat and tidal action) have not deterred growers; they have simply evolved their practices to overcome the hurdles placed in their way.

Canadian mussels are grown in waters that have been certified safe for shellfish production and the product is sampled and monitored continuously to ensure its safety for consumers. Many of the primary mussel processors are one component of vertically integrated mussel holdings which include seed production, growout, and processing facilities.

Issues Facing the Industry

Leasing Issues

While some provinces are supportive of developing an aquaculture sector and recognize the direct benefits that are derived by the surrounding rural communities there is still a lengthy and often costly process involved in obtaining new sites. Efforts have been made to streamline the process, make transparent the requirements and move forward with site approvals. This being said, the price to an individual shellfish grower to complete an environmental assessment on each site may be cost prohibitive, depending on local conditions and jurisdictions. It is important to ensure new sites are available so that the industry can attract new entrants to sustain the long-term viability of the sector.

Competition for Access to the Resource

While much of Canada's coastline is ideal for mussel culture, the industry must compete with other sectors for use of the aquatic resource. Mussel aquaculturists have done much to be recognized as having equal rights to the resource with the more traditional uses (commercial and recreational fisheries, commercial and recreational boating) as well as to new emerging stakeholders (other aquaculture species and First Nations treaty claims).

Environmental Issues

Canadian mussel growers have been fortunate to have access to the pristine waters of Canada's shoreline for production of quality products. However, ongoing effort is required to ensure that the resource they utilize is not compromised by upland practices. While many Canadian mussel growers are participants in environmental codes of practice or management regimes, the ever changing environmental conditions (climate change, water quality, etc.) are indeed a challenge for growers.

Invasive Species

Canadian mussel aquaculturists, much like their international counterparts, are impacted by invasive species. The introduction of species without natural predators in the system can have a detrimental impact on the industry, as is being experienced in some areas of Canada. It is critical that the regulators and the public are aware of the magnitude of the problem and that processes and solutions are developed to manage or mitigate this situation.

Market Access Issues

There are several market access issues that face the Canadian mussel industry, including post September 11 impacts (decrease in consumption of some shell-

Mussel farmer with recently deployed socks

fish products, increased border security and regulations), the establishment of monitoring and zoning systems to continually meet ever-changing world trade demands, and the development of new markets as well as the continued advancement of value-adding technology.

Science and Monitoring

Canadian mussel growers may be faced with multiple challenges to meet the demands placed on them by today's ever-changing environment. However they have been quite supportive of the research and development initiatives required and continue to support the required efforts both with their financial and other (boats, gear, crews, knowledge, product, etc.) resources.

Conclusion

The aquatic resource is available along the coastline of Canada to support future growth of the mussel industry. The continued good will of the rural communities in which the Canadian mussel industry is a vital component, an on-going commitment from the various levels of government and the continued ingenuity and persistence of the industry will ensure that Canada's mussel industry is well situated to continue to contribute its fair share of high quality product to the marketplace.

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Mussel longline layout providing wide navigation channels and ease of access to the site

Effects of Biofouling by *Ciona intestinalis* on Suspended Culture of *Argopecten purpuratus* in Bahia Inglesa, Chile

E. Uribe and I. Etchepare

Settlement and growth of the ascidian *Ciona intestinalis* during spring and summer has had a major deleterious effect on suspended culture of the scallop *Argopecten purpuratus* in Chile.

Introduction

Settlement and growth of the ascidian *Ciona intestinalis* (L.) during spring and summer has had a major deleterious effect on suspended culture of the scallop *Argopecten purpuratus* in Chile. Major declines in daily production have been experienced, with serious deterioration and loss occurring among the more than 300,000 suspended culture units maintained by one company within its marine concession. Of the 105,000 units fouled by *C. intestinalis,* more than 50,000 units collapsed. Complete fouling of scallop culture systems significantly raised production costs and caused high mortality when dissolved oxygen and planktonic food became limited due to the decrease in water circulation through the pearl nets and lantern nets.

Material and Methods

Suspended culture units belonging to Cultivos Marinos Internacionales S.A. at Bahía Inglesa, Chile (27°03′S; 70°51′W) (Fig. 1) were monitored through various stages of the culture process for the accumulation of biofouling due to *Ciona intestinalis.* Sampling was carried out biweekly from August to November 1994 on units (pearl nets and lantern nets) installed in longlines 7 m deep. The degree of settlement of *C. intestinalis* on culture systems was measured using a qualitative scale based on 9 discontinuous classes related to the size of the individual fouling organisms and the extent of coverage of the culture unit (classes: 1A, 1B, 1C, 2A, 2B, 2C, 3A, 3B, 3C). The accumulation of *C. intestinalis* was rated on an arbitrary scale of the 9 nine classes depending on the degree (A = low, B

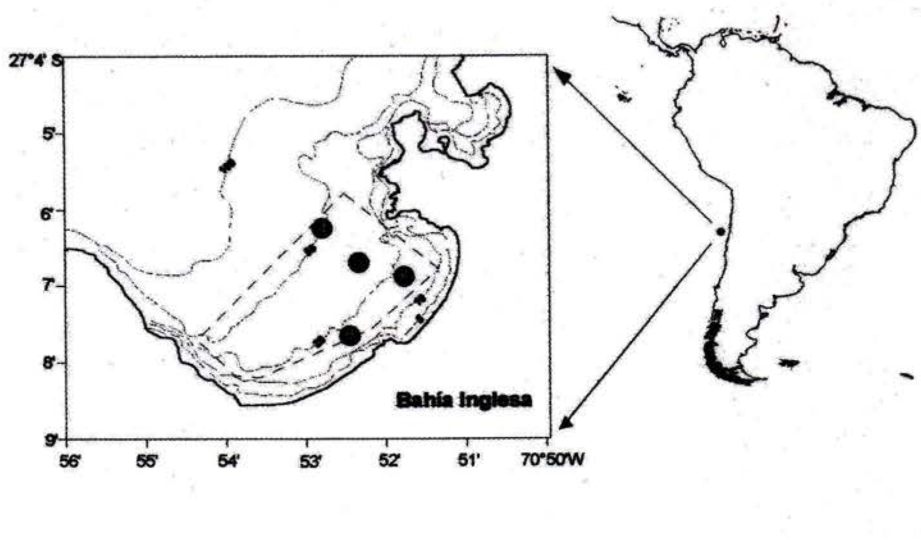

Figure 1. Scallop culture area in Bahía Inglesa and Oceanographic stations.

= mild, C = high) of fouling and typical length of the ascidians (1 = < 3 cm, 2 = 3-7 cm, 3 = > 7 cm). For example, class 1A was lightly fouled, with specimens less than 3 cm in length, 2B was moderately fouled, with specimens 3-7 cm in length, etc. At a representative station in Bahia Inglesa we measured temperature and dissolved oxygen (YSI brand dissolved oxygen meter) at depths of 0 to 25 m (5-m intervals) on a daily basis. Water samples were collected with Niskin bottles at depths of 0, 5, and 15 m for qualitative and quantitative analysis of the phytoplankton using the Utermöhl (1958) method for total phytoplankton (µgC/L). Water transparency was determined using a Secchi disc.

Results and Discussion

Of the total number of units monitored (5392) over a 3-year period (January 1995 to November 1997), 42.45% showed settlement of *C. intestinalis* at a basic level (Class 1A = 28.15% + 1B = 14.30%), with individuals < 3 cm and partial coverage only. About a fifth (19.50%) of the system showed maximum coverage by fouling, including individuals 3 to 7 cm in length (class 2C and 3C). In the latter condition, the culture units were 100% covered by *C. intestinalis* and mortality of contained scallops occurred due to anoxia and lack of food (Fig. 2).

During the study period, environmental conditions were highly variable due to effects related to the 1996 climatic anomaly "La Niña" at the beginning of May, and the beginning of "El Niño" in May 1997. The effects of these anomalies can be seen in the thermal structure of the water column. The years 1994-95 were considered normal for the region and the summer surface water temperatures exceeded 18ºC and decreased with depth to 13ºC at 25 m. Also during this season, several peaks of cold, low oxygen waters (< 2 mg/L) were observed, which indicated active upwelling. Fertilization of bay waters by these events was evident from the low Secchi disc readings at a 5-m depth and were confirmed by the high phytoplankton biomass (above 200 µgC/L). These upwellings led to phytoplankton biomasses as high as 500 µgC/l between the spring of 1995 and the fall of 1996. From August 1996 to January 1997 a thermal anomaly was observed in the water column due to effects from "La Niña", with temperatures < 12ºC below 10 m depth. In this period, the dissolved oxygen values were high (> 9 mg/L in almost all the water column). Also, transparency values exceeded 10 m, and phytoplankton biomass values showed a greater frequency of values below 50 µgC/L. In May 1997 a positive thermal anomaly was observed due to an "El Niño" phenomenon in which temperatures in the water column exceeded 14ºC during the winter months. In contrast to the preceding year, oxygen values declined to below 8 mg/L in the water column. Also,

Figure 2. *Ciona intestinalis* creates serious fouling problems in lantern nets used for scallop growout, producing high mortality.

transparency values were greater than 10 m and phytoplankton biomass was poor, which is a characteristic of the "El Niño" phenomenon for this study area.

In spite of some variation in the percentage of culture units affected, settlement or colonization by *C. intestinalis* occurred uninterrupted over the time period of the study (January 1995 to November 1997).

In 1995, of a total of 1818 samples that showed fouling by *C. intestinalis*, 16% had total coverage at levels 2C and 3C. A similar situation was observed in 1997, when 15% of the samples showed total coverage. However, in the second half of 1997, from winter until the beginning of summer, there was a low rate of settlement of *C. intestinalis* (0.31%), possibly due to the effects of the "El Niño" phenomenon in the region. The situation in 1996 differed from other years in that of the 2471 samples observed, 24% showed total coverage, probably related to the high biomass of phytoplankton (over 500μgC/L) observed in the summer of that year in addition to the favourable conditions for the growth of *C. intestinalis* on the culture system. Thus, over the last three years an average of 19.5% of all culture units had critical fouling levels (total coverage). Lantern nets that have a normal weight of 12 kg weighed more than 120 kg after three months of culture. Losses of scallops were high between November 1995 and March 1996, with a 69% loss of specimens measuring 5 to 10 mm, and a 31% loss of those with a median size of 10 to 35 mm and those larger than 35 mm.

The highest losses of scallops occurred when the culture units were entirely covered with fouling (classes 2C and 3C) and when the phytoplankton biomass exceeded 500 μgC/L. Both factors limited the dissolved oxygen available to the scallops, due to the lack of water circulation through the mesh of the nets and the depletion of oxygen by the phytoplankton present in the water column.

Over the 3-year period, newly-immersed culture units took about 45 days to show initial fouling and 100 to 125 days to reach the highly-fouled 2C condition that is critical for the survival of the scallops. The intermediate culture system (pearl nets), as well as those for grow-out (lantern nets) became fouled in less than 40 days in the late spring of 1995, the spring of 1996 and the early summer of 1996, including some cases that occurred within 15 to 20 days, which coincides with the major fouling coverage in the culture units. A similar situation, although not as severe, was experienced by the culture systems immersed in the autumn of 1996. The timing of the fouling is due mainly to the high biomass of phytoplankton present at that time of the year in the water column and considering that *C. intestinalis* is an efficient filter feeder.[1]

The relationship between high phytoplankton biomass (> 10 μgChl/L) and high population density of *C. intestinalis* was reported by Riisgard et al.[2] during spring and fall in Kertinger Nor, Denmark. Petersen et al.[3] in laboratory experiments fed *C. intestinalis* a microalgal concentration of 150 to 250 μgC/L and obtained a maximum growth of 2.5% length per day which was much lower than that registered in the natural environment where growth can reach 7 to 9% length per day, since coastal waters offer a greater availability of food.

Aquaculture systems placed in the ocean during the spring of 1995 were invaded within 70 to 90 days, some reaching total coverage, indicating that the juvenile ascidians grew from a size of < 2 cm to the > 5 < 7 cm class in 35 to 50 days, suggesting a growth rate of 0.84 to 1.83 mm/day under the optimum oceanographic conditions that were present in 1995 and the summer of 1996. Linear growth of the ascidians from < 2 cm to the 5 to 7 cm size thus varied with season and oceanographic conditions from 0.6 to 1.2 mm/day, with an average of 0.63 mm/day, a similar situation to that found by Yamaguchi[6] in Japanese waters.

A different case was observed for culture units immersed in the spring 1994, as these were covered totally with *C. intestinalis* after 4 to 6 months in the water (units which were not removed from water). Growth rates of the ascidians, when calculated from their estimated size at settlement (0.35 mm) to the 5 – 7 cm size class (2C) varied from 0.4 to 0.7 mm/day (mean = 0.53 mm/day), over periods from 94 to 147 days in the sea (mean = 115 days).

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A Vision for Canada's Mussel Industry: Aquaculture Development that will Respond to the Challenges of the New Frontiers

Yves Bastien

Mussel culture in Canada is undergoing continuous change and globalization is an important aspect of this sector of the aquaculture industry. Public scrutiny is on the rise and environmental and social concerns continue to influence cultivated products in Canada. The mussel industry is no exception. We have withnessed increased emphasis on environmental sustainability, use conflicts, food safety, and industry competitiveness to name a few. How will Canada adapt and take advantage of the new opportunites and challenges emerging in its mussel industry? To remain vibrant, the industry and both levels of government must explore new ways, point to new directions and deal with these new challenges. Strong national leadership coupled with increased communications with all stakeholders in addressing issues of concern is required. Governments in this country need to adapt and provide a more enabling environment. An in depth reform of the regulatory and social frameworks, implementation of innovative policies, and well designed programs and services are fundamental elements of the development of innovative solutions. Examples include farm risk management, food safety, R&D and shellfish health programs. Building a vision for aquaculture development in Canada for the next 15 years will provide the necessary roadmap to respond effectively to the mussel industry's new frontier challenges.
[Aquaculture Commissioner, Office of the Commissioner for Aquaculture Development, Ottawa, Canada]

Submerged Longline Culture of Blue Mussels in Exposed Oceanic Environments

R. Langan and C. Horton

The University of New Hampshire has established an open ocean aquaculture demonstration site 8 km from shore in the open waters of the Gulf of Maine, USA. It is a deep-water (52 m) site that is fully exposed to wind and waves from all directions and can experience significant wave heights of 9 m during severe storms. The shellfish culture component of the project consists of two submerged longlines, each approximately 120 m in length, with the horizontal headline submerged 15 m below the surface. The project was designed to identify and demonstrate offshore commercial aquaculture opportunities for local and regional capture fishing communities; therefore a fishing vessel typical of those used in nearshore ocean fisheries was equipped to handle submerged longlines. Gear and technology used in inshore longline culture was modified for use in the open ocean environment. Since 1999, five seed cohorts of blue mussels have been grown to market size with an average production cycle of 13 months from spat settlement to

55 mm shell height. Yield at market size ranged from 7.5-12 kg/meter of mussel rope, depending on the initial seeding density. The product quality and meat yield has been consistently excellent, with cooked meat weights ranging from 42% to greater than 55% of whole cooked weight, depending on density and season. Project results indicate a strong potential for offshore commercial development.
[Cooperative Institute for New England Mariculture and Fisheries, Environmental Technology Building, University of New Hampshire, 35 Colovos Road, Durham, NH 03824 USA]

The Trend of Global Warming— What Could it Mean for Mussel Production?

Doug MacLeod

Mussels can play an important role in the environmental degradation that may result from global warming. Increases in water temperatures and increases in nutrient loading will result in greater potential for eutrophication of estuarine environments. Mussels, being filter feeders, can use this source of food production and as a result improve water quality and thus the environment. However, the new frontier is never that simple because significant increases in mussel production must be matched with equal investments in marketing.
[European Mollusc Producers Association, Isle of Skye, Scotland]

Mussel Culture in Exposed Areas along the Irish Coast

Terence O'Carroll

As protected bays and estuaries become developed by mussel aquaculture and competing activities, more focus will be placed on exposed locations. Numerous issues will need to be addressed including the type of culture gear, how well mussels will attach to the lines, biotoxins and the logistics of working sites that may only be accessed in certain weather conditions. The potential for exposed sites to be used for a portion of the grow out cycle should also be considered. Development of exposed sites must be conducted with economic viability in mind.
[Irish Sea Fisheries Board, Co Dublin, Ireland]

Mussel Hatcheries— A Part of the New Frontier

Gordon King

Constrained by regulation and lack of permitable locations for nearshore suspended culture, the United States will not likely be a major contributor from a volume standpoint to world mussel production in the foreseeable future. However, from a technology standpoint US bivalve hatchery technol-

ogy is already shaping the future of mussel production in other parts of the world. Hatcheries enable the industry to produce seed consistently at a predictable price. They provide the ability to work with triploidy to avoid seasonal variations in yield and shelf life and they provide the ability to work with genetic selection to increase growth rates, yields and disease resistance. These advances have other countries looking to the northwest United States for seed and/or technology.
[Taylor Shellfish Company, Washington State, USA]

Mussel Farm Servicing at the "New Frontiers"

Rob Pooley

The tyranny of the minority (i.e., the conservation movement) has seen the New Zealand Mussel industry left with two options for growth. Firstly enhancing and adding value to our existing industry; secondly, pioneering new sites "somewhere over the horizon" where we can't be seen or heard. We are now forced to leave the comfort of the sheltered glacial valleys of the Marlborough Sounds, and consequently we are in the process of developing all new mussel farm servicing vessels and technology.
[Elaine Bay Aquaculture Ltd, Box 697, Nelson, New Zealand]

Problems with Non-Indigenous Species

Dealing with an Aquatic Invader: The Clubbed Tunicate (*Styela clava*) in Prince Edward Island Waters

F. A. Boothroyd,[1] N. G. MacNair,[2] T. Landry,[3] A. Locke,[3] T. J. Davidson[4]

In 1998, the clubbed tunicate, *Styela clava*, was first reported in Prince Edward Island waters. Since that time its population has increased significantly in three areas and it has had a significant negative economic impact on the cultured mussel industry. Recently, the *Styela clava* Action Research Group (SCARG) was formed to conduct and coordinate research on the tunicate. Members of the group come from the federal and provincial governments, university and industry. The research follows four main lines of investigation: Reproductive biology, Ecosystem interactions, Epidemiology, and Treatments. Among the group's findings are the following: the ovaries and testes are developing synchronously; larvae are able to survive in water temperatures as high as 30° C and as low as 10° C; the presence of tunicates results in reduced mussel meat yields; the range in PEI waters appears to be restricted to three estuarine systems; and treatments for tunicates include dips in hydrated lime, brine and acetic acid sprays although inconsistencies exist with all treatment studies.
[1) PEI Aquaculture Alliance, 96 Kent Street, Charlottetown, PEI C1A

1M9 Canada 2) PEI Department of Fisheries, Aquaculture and Environment, PO Box 2000, Charlottetown, PEI C1A 7N8 Canada 3) Fisheries and Oceans Canada, Gulf Fisheries Centre, Moncton, NB E1A 9B6 Canada 4) University of Prince Esward Island, 550 University Avenue, Charlottetown, PEI CIA 4P3 Canada]

On the Ecology of the Invasive Ascidian *Styela clava* in Southern New England Coastal Waters: The Lessons We Learned Over the Past 20 Years

Robert B. Whitlatch

The invasive solitary ascidian *Styela clava* first appeared in Long Island Sound, CT in 1973. The species rapidly expanded and has become a predominate member of shallow water epifaunal assemblages in harbors throughout much of southern New England. It is most commonly found on many different types of hard substrates (e.g, piers, floating docks, buoys, lines, lobster traps) where densities of 5-15 individuals per 100 cm^2 are not uncommon. Since its arrival, we have been studying various aspects of the ascidian's life history and its potential impacts on the ecology of southern New England coastal waters. These studies have included: (a) long-term recruitment dynamics and growth studies of the ascidian, (b) examination of predator effects on *Styela*, (c) effects of *Styela* on eastern oyster (*Crassostrea virginica*) and blue mussel (*Mytilus edulis*) larval mortality, post-settlement survival and growth, and (d) the role the ascidian is having on the distribution and abundance of other resident fauna in southern New England. An overview of these studies will be presented in light of the expanding distributional range of the species along the eastern seaboard of North America.
[Department of Marine Sciences, University of Connecticut, Groton, CT 06340 USA]

Ascidians: Ecology and Biology of a Competitor to Mussels

Jens Kjerulf Petersen

Sessile ascidians or sea-squirts are well known as fouling organisms throughout the world. To be able to understand the potential damage ascidians can cause to mussel growers it is necessary to know how they work. The presentation reviewed the biology and ecology of ascidians, with emphasis on feeding biology and spread of offspring. The propagation of a population of *Styela clava* to European waters was used as an example of the worldwide spread of ascidians.
[Department of Marine Sciences, University of Connecticut, Groton, CT 06340]

Fall Staging and Foraging Behaviour of Diving Ducks in Relation to Mussel Cultivation in Prince Edward Island

M. Dionne,[1,2] D. J. Hamilton,[1, 2] A. W. Diamond,[1] and G. J. Robertson[3]

Blue mussel cultivation on Prince Edward Island contributes $35 to 40 million to the Island economy. In recent years, especially during the fall migration period, interactions between diving ducks and cultivated mussels have increased. Habitat for staging ducks overlaps with an expanding mussel industry, resulting in a greater level of disturbance for waterfowl and crop losses for growers. Predation by diving ducks, especially greater scaup *(Aythya marila)* and long-tailed ducks *(Clangula hyemalis)* now costs the industry $1-2 million annually. Using a series of manipulative experiments and behavioural observations, we are quantifying the relationship between ducks and the industry, and attempting to develop non-disruptive techniques to mitigate negative effects. Specifically, we are assessing effects of ducks on mussels socked at different sizes and densities, quantifying effects of mussel culture on behaviour and activity patterns of ducks, identifying preferred prey sizes for ducks, and testing a protective socking material that may alleviate the problem. Historical survey data on the staging and wintering areas of ducks is also being analysed in relation to expansion of the mussel industry. Preliminary results suggest that ducks prefer small mussels but are capable of taking seed of all sizes. Mussel shake-off appears to be a major issue only with greater scaup.

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A Stage-Based Matrix Model for Cultivated Mussels (*Mytilus edulis*) in Prince Edward Island

J.-S. Lauzon-Guay, M. Barbeau, and D. Hamilton

Blue mussel cultivation on Prince Edward Island is a major industry contributing to $35 to $40 million annually and employing 1500 people. However, in recent years predation by diving ducks has become problematic for mussel growers. The loss of mussels to ducks has been estimated at $1 to 2 million annually. In order to assess the problem and to analyze different solutions, two experimental leases were socked with mussel seed. A total of 12 different treatment combinations were used: 3 initial mussel sizes, 2 densities, and presence or absence of exclusion cages. Growth and survival of mussels is being monitored throughout the study period. This will indicate the number of mussels lost to ducks under different conditions and the response of mussels to these growing conditions. Using data obtained during the first year of the study, a stage-based matrix model will be constructed and yield will be predicted using different growing strategies. The model prediction will then be tested during the second year of the study, using a

new set of socks. Results will provide mussel farmers with possible solutions for reducing duck predation at mussel leases and optimizing growing conditions.

[University of New Brunswick, Biology Department, Bag Service #45111, Fredericton, NB E3B 6E1 Canada]

Shellfish Health and Environment

Disseminated Neoplasia of *Mytilus trossulus*

James D. Moore

Disseminated neoplasia, also known as haemic neoplasia, is a leukemia-like disease of numerous species of bivalve molluscs worldwide. In eastern Pacific *Mytilus trossulus*, the disease causes significant mortality in all age classes. Similar if not identical conditions have been reported in *M. trossulus* from other geographic regions throughout the northern hemisphere. Disseminated neoplasms are rare to absent in *M. edulis* and *M. galloprovincialis,* including individuals from locations where the disease is common in *M. trossulus*. The lower prevalence in *M. galloprovincialis* has been an important factor in the shift from *M. trossulus* to *M. galloprovincialis* as the species of choice for aquaculture in Washington state. Flow cytometric DNA content analyses demonstrated that neoplastic cells in *M. trossulus* from British Columbia, Washington and Oregon have a distinct G_0G_1DNA level of either tetraploid (4n) or approximately pentaploid (5n). The two forms appear to arise from discrete transformation events that result in independent pathogenetic sequences. One unique feature of this disease within the realm of oncology is that the primary mode of spread between individuals appears to be direct transplantation of intact cells. The neoplastic features of these cells make them excellent candidates for source material to establish the first marine invertebrate cell line.

[California Department of Fish and Game, UC Davis Bodega Marine Laboratory, 2099 Westside Road, Bodega Bay CA 94923 USA]

Eutrophication: Cause and Effect in Relation to Mussel Farming

Jens Kjerulf Petersen

Supply of nutrients to coastal waters from land run-off or atmospheric deposition will result in increased primary production. This provides the basis for increased mussel production and it has been seen in Danish waters that mussel yield has increased during the last century. Eutrophication can, however, also lead to increased problems with oxygen depletion in bottom water killing benthic organisms below the stratification. This may also affect mussel production. Mussel farming may thus be affected by eutrophication and can in addition be a key parameter in mitigating the effects of

eutrophication.
[Department of Marine Ecology, Ministry of Environment and Energy, Frederiksborogvej 399, Box 358, DK-4000 Roskilde, Denmark]

Mussel Culture

Development and Evaluation of Standardised Monitoring and Data Acquisition Systems for the Management of Mollusc Culture in Atlantic Canada

T. Landry,[1] *J. Davidson,*[2] *L. Comeau,*[1] *M. Hardy,*[1] *and R. Thompson*[2]

Blue mussel (*Mytilus edulis*) aquaculture in Prince Edward Island (PEI) began in the 1980s and grew into a $25 million a year industry in the 1990s. This expansion can be attributed to an increase in the number of mussel grow-out sites and also to a rapid development of husbandry practices specific to Atlantic Canada. Presently, there remain almost no available grow-out sites that can support mussel culture on the Island, and production yields can vary substantially from one site to another, and also from one year to the next. It remains unclear as to whether this variability in performance is due mainly to environmental factors or husbandry practices. The first objective of our study is to develop a system for the monitoring of natural growth rates and physiological condition of bivalves. This system will enable producers to compare the year-to-year performance of their own operation with the natural growth conditions inside the bay. The second objective is to develop a data acquisition system at the producer level. Detailed information on husbandry practices and production yields will be collected in a standardised format and transferred to a central database. The database will be accessible by the producer, and will let him/her compare the productivity of their farm with bay scale means and trends. The resulting information will be used to develop a greater understanding of the performance of mussel aquaculture sites throughout PEI.
[1) Fisheries and Oceans Canada, Gulf Fisheries Center, Moncton, NB E1C 9B6 Canada 2) University of Prince Edward Island, Faculty of Veterinary Medicine, Charlottetown, PE C1A 4P3 Canada]

Nutrient Uptake and Release from Fouling Organisms Associated with Cultured Mussels in Tracadie Bay, PEI

A. R. LeBlanc,[1] *G. Miron,*[1] *and T. Landry*[2]

Fouling organisms are causing concerns among mussel growers in PEI, Canada. Most of these foulers are sedentary filter feeders, and are therefore a potential competitor with mussels for resources. This could translate into a reduction in meat yield in mussels. We carried out an experiment to deter-

mine the relative impact of fouling organisms on the uptake and release of nutrients. Chlorophyll *a*, ammonium, phosphate, nitrate, nitrite, silicates and suspended particulate matter were investigated. This study showed that foulers had only a small effect on nutrient use. There were some significant differences in chlorophyll *a* uptake between mussels/foulers and mussels. The mean chlorophyll *a* uptake by mussels/foulers was 1.56 ± 0.45, 3.41 ± 0.38 and 5.65 ± 0.42 µg/L, while for mussels it was 1.47 ± 0.33, 5.06 ± 0.53 and 3.36 ± 0.33 µg/L for each of the experiments. Ammonia release was 0.86 ± 0.13, 3.12 ± 0.28 and 0.76 ± 0.16 µg at-N/L for mussels/foulers and 0.41 ± 0.32, 0.73 ± 0.06 and 0.56 ± 0.05 µg at-N/L for mussels for each experiment. There was no significant use of suspended matter. A temporal and spatial investigation of foulers was also carried out.
[1) Université de Moncton, Moncton, NB E1A 9B6 Canada 2) Department of Fisheries and Oceans, Science Branch, Maritimes Region, Gulf Fisheries Center, P.O. Box 5030, Moncton, NB E1C 9B6 Canada]

Effects of a *Schizochytrium*-Based Diet in the Growth and Nutritional Condition of the Mussel, *Mytilus galloprovincialis*

J. N. C. (Ian) Whyte,[1] Kathleen Sherry,[1] Norma Ginther,[1] and Guillaume Peribere[2]

Juvenile mussels were fed for 120 days with live algae *Chaetoceros muelleri* and *Isochrysis galbana* (T-iso) at 1:1 (w/w); a mix of live algae and *Schizochytrium* at 1:1 (w/w); and 100% *Schizochytrium*. Although similar in total available energy the macronutrients differed mainly in the higher 20% carbohydrate and lower 45% protein in *Schizochytrium* relative to 10% and 54% in the live algae diet. Length and dry weight of the mussel increased linearly with feeding. AFDW increased at 3.85, 3.02, and 2.01 µg/mussel/d and production of protein at 2.79, 2.12 and 1.74 µg/mussel/d for mussels fed the mixed diet, *Schizochytrium*, and live algae, respectively. Total energy increased in mussels fed the mixed diet, *Schizochytrium*, and the live algae by 59.5, 47.7 and 34.5 mJ/mussel/d. Total energy was higher in *Schizochytrium*-fed mussels than those fed the other diets at d_{70}, but from d_{70} to d_{120} the most energy competent mussels, with the highest protein content, were those fed the mixed algae–*Schizochytrium* diet. Availability of metabolic energy and accessibility to amino acids from dietary proteins controlled the biosynthesis of protein in juvenile mussels. *Schizochytrium* sp. with 20% carbohydrate increased rapidly the metabolic energy in the mussel, but the dietary protein was less effective than that in live microalgae at providing available amino acids. The fatty acid profiles of the mussels reflected the dietary fatty acids supplied. The ratios of fatty acid concentrations in mussels to those in the 3 diets suggested selective attainment to a steady state concentration of individual acids, with excess dietary acids being egested. Conservation of fatty acids in mussel tissue was evidenced by the rate of catabolic depletion of fatty acids in tissue of mussels starved for 120 days.
[1) Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, BC V9T 6N7 Canada 2) Island Sea Farms Inc., Box 445, Ganges, Saltspring Island, BC V8K 2W1 Canada]

Increasing Existing Mussel Farm Production Capacity by Increasing Production Yields with Mussel Discs™

I. Jefferds

Efforts to increase mussel farm production generally result in the expansion of on-site capital facilities, such as building new longlines or rafts on existing farm leases until such time as the lease area is full, and this usually leads to further efforts to expand the existing lease area or to obtain new leases. At a time when presumed carrying capacity, visual aesthetics and navigation issues become limits to expansion in aquaculture lease areas, an economic alternative to building new grow out facilities is to increase production yields or efficiency on existing longlines or rafts through the use of Mussel Discs.™ Mussel Discs™ are an improvement on the proven Spanish idea of placing pegs in the mussel socks or lines to prevent mussels from sloughing off the lines during storms or at harvest time. The proven use of Mussel Discs™ to stabilize and prevent the loss of harvest size mussels on mussel socks or lines has been shown to increase production yields up to and beyond 50 percent, and they may be easily incorporated in to existing mussel farm sites and thus limit the need for additional longlines or rafts.
[Penn Cove Shellfish, LLC, P.O. Box 148, Coupeville, WA 98239 USA]

Impacts of Secondary Set on Growth and Yield of Commercial Blue mussels (*Mytilus edulis*) in Iles-de-la-Madeleine (Québec)

F. Bourque and B. Myrand.

In the fall of 2001, 25 sleeves (1-year-old) with various levels of secondary set were each divided into three parts: the first was used to characterize the importance of secondary set at this moment, the second was delicately stripped by hand of its secondary set, and the third was kept untouched. The last two parts of each sleeve were suspended from a longline. Six months later (May 2002), the mass of secondary set on some sleeves (up to 9 kg/m) was higher than that of commercial-sized mussels. No significant differences could be found among the sleeves in terms of mean shell length. It seems that sleeves harvested within one year after spat settlement do not suffer direct negative impacts from secondary set in terms of growth of mussels. However, we found a significant realtionship between the intensity of secondary set and the yield (dry weight). The impacts were noticeable after a certain threshold, as 85% of the paired sections showed significant differences between cleaned and intact sections when the volume of secondary set was > 2.5 L/40 cm.
[Station technologique maricole des Iles-de-la-Madeleine,
Cap-aux-Meules, QC G0B 1B0 Canada.]

Seasonal, Geographic and Species Differences in the Physical Properties of Shells in Newfoundland Cultured Blue Mussels (*Mytilus* spp.)

Alistair Struthers,[1] *Cyr Couturier,*[1] *Susan Hynes,*[1]
David Innes[2] *and Danielle Nichols*[1]

Previous studies on differences between *Mytilus edulis* and *Mytilus trossulus* have been limited to single populations and have made no attempt to compare shell characteristics relating to culture performance. The present study examined physical properties of cultured mussel shells over wide geographic distances, throughout the primary growth season, and by species. Commercial-size mussels were collected from mixed populations and subjected to a standardized mechanical impact test, simulating primary processing activities, and the relative proportions of shell breakage patterns measured. Physical properties (shell thickness, morphometrics and % organic content) of the shells were measured and compared to the breakage patterns. Mussels were genotyped with high-resolution DNA electrophoretic protocols. Results showed seasonal and geographic (stock) differences in shell mechanical properties and breakage patterns. The patterns are related to shell thickness and organic content. There are no consistent patterns in species differences for shell properties, suggesting production performance under culture is not influenced by species. In conclusion, simple measures can be taken to evaluate mechanical properties of shells, and these measures may be used in determining handling practices at seeding, harvest and post-harvest stages. Further, the hypothesis that cultured *M. trossulus* have weaker shells than *M. edulis* is not supported.
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Field-Based Production Trials Comparing Triploid and Diploid *Mytilus edulis*

John Brake,[1] *Jeffrey Davidson,*[2] *Jonathan Davis,*[3] *and Garth Arsenault*[2]

Triploid shellfish are of commercial significance because they are sterile and retain product quality during and after the spawning period. Field evaluations of diploid and triploid mussels demonstrated that triploids had a greater growth rate than diploids. The growth difference was evident in the first growing year after sock deployment in highly productive waters. This difference was not detectable in less productive waters until the second year after sock deployment, suggesting possible differential growth of triploids versus diploids, related to environment. Diploid mussels in the less productive waters were notably less sexually mature in the first year; therefore the differential performance of triploids between test sites may have been related to spawning. After eleven months in the field triploids had a mean shell length 1.05% ($p = 0.48$) larger than diploids in the less productive waters versus 8.09% ($p < 0.001$) larger in the highly productive waters. Triploids examined after a spawning event showed no histological evidence of spawning, while 71% of diploids showed some evidence of spawning. A maximum observed increase in dry tissue weight of 62.82% and a mean

shell length increase of 10.95% were observed when triploids were compared to diploids after the local spawning event. Shell length, relative soft tissue weight, and condition index were all higher in triploids. As well, a highly skewed sex ratio was evident, showing a highly male-dominant sex ratio in triploid mussels.
[1) Oregon State University, 2030 South Marine Science Drive, Newport, OR 97365 USA 2) Department of Health Management, University of Prince Edward Island, 550 University Avenue Charlottetown, PE C1A 4P3 Canada 3) Baywater, Inc., 15425 Smoland Lane, Bainbridge Island, WA 98110, USA]

Nutrition, Processing and Product Quality

Minor Fatty Acids and Unsaponifiables in the Common Mussel

R. G. Ackman

The most important marketing tool for blue mussels (*Mytilus edulis* L.), aside from their being delicious, is their n–3 fatty acid content. Among 40 fatty acids in two analyses, EPA was 18% and DHA 12%, a very desirable ratio. The proportion of unsaponifiables recovered from the total lipids was 12%, about which we know little, although sterols have been much studied. Two lots of local mussels were examined for phytol (3,7,11, 15-tetramethyl-2-hexadecen-1-ol), part of the algal chlorophyll, as a possible contributor to meat flavor. Phytol was present at about 0.003% of organic tissue, and dihydrophytol possibly present at about 0.001%, whereas 12:0, 14:0, 16:0, 18:0 and 20:0 linear fatty alcohols totaled twelve times as much. It is concluded that in filter-feeding bivalves phytol from algae must be rapidly catabolized, converted to hydrocarbons, or to isoprenoid fatty acids, and is itself unlikely to provide a strong flavor component. The hydrocarbon pristane derived from phytol also should not affect flavor. It is useful as an indicator of the nutritional status since it reflects the total algal intake of phtyol.
[Canadian Institute of Fisheries Technology, Dalhousie University, P.O. Box 1000, Halifax, NS Canada B3J2X4]

Quality Changes of Cultured Newfoundland Blue Mussels (*Mytilus Edulis*) at Pre- And Post-Harvest Stages

M. A. Khan,[1,2] *C. C. Parrish,*[2] *F. Shahidi*[1] *and C. McKenzie*[3]

The objectives of this research were to: (1) examine seasonal variation of nutritional and microbial qualities of Newfoundland blue mussels cultured at various locations, (2) evaluate quality changes of commercial size blue mussels stored on ice, and (3) modify current methods in quality evaluations. One-year-old mussels were cultured at four stations in Newfoundland. The mussels were grown for an additional 17 month period and thereafter harvested. Seasonal variations were monitored using lipid and microbial indices. Fatty acid composition of lipids was determined by gas chromatography. Sterol composition was determined using gas chromatogra-

phy-mass spectroscopy. Modified plate count agar technique was used for microbial analysis, which was also used to evaluate the microbial quality of the final product stored on ice. Changes in flavor quality were assessed using a modified thiobarbituric acid reactive substances (TBARS) test. Slight nutritional and microbial quality differences were observed among mussels cultured at different stations. Higher oxidative stress of stored blue mussels affected their flavor quality. Furthermore, microbial shelf life of the stored mussels was up to 10 days. Results from this study may be used to devise appropriate steps for maintaining the premium quality of blue mussels at pre- and post-harvest stages.
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Influence of Agar type and Storage Temperature on Microbial Shelf Life Estimation of Commercial Size Cultured Newfoundland Blue Mussels *(Mytilus edulis)*

M. A. Khan,[1,2] C. C. Parrish,[2] F. Shahidi[1] and C. McKenzie[3]

The objectives of this study were to: (1) estimate microbial shelf life of cultured Newfoundland blue mussels stored at various temperatures using bacterial counts on plate count agar (PCA) and marine agar (MA), and (2) establish the relationship between the bacterial counts using regression analysis. Cultured blue mussels were stored at −12°, 2° and 9°C for 10 days. Samples were removed at specific intervals and the shelf life was estimated using total heterotrophic bacteria (THB) and psychrotrophic bacteria (PB) counts on PCA and MA. Bacterial counts on MA were 1-3 log colony forming units (CFU)/g higher than their corresponding counts on PCA agar. Therefore, shelf life based on THB and PB counts on MA was 3-4 days less than that estimated using THB and PB counts on PCA. Strong correlations ($r > 0.7$, $P < 0.01$) were observed between bacterial counts of cultured mussels stored at 2° and 9° C on PCA and MA. Both temperature and agar type greatly influence the estimation of the shelf life of cultured blue mussels. Therefore, it is suggested that the use of PCA to evaluate the microbial quality of cultured mussels and similar types of seafood be replaced with MA.
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Evaluation of the Neutral Red Assay as a Stress Indicator in Mussels *(Mytilus* spp.) in Relation to Processing Activities and Post-Harvest Storage Conditions

Joanne Harding,[1] Cyr Couturier,[1] G. Jay Parsons[1] and Neil W. Ross[2]

Cultured bivalves are subjected to a variety of physical and environmental conditions during farming activities. Some conditions lead to stress and re-

duced performance or quality. The goal of this study was to evaluate stress indicators in mussels in order to improve processing and post-harvest storage conditions. The neutral red assay (NRA) measures retention time of the neutral red dye in the hemocyte organelle, the lysosome, which can be inversely correlated to the overall stress of the mussel. Shelflife also provides an indication of mussel stress status. The objectives of this study were to evaluate mussel stress in relation to 1) processing practices, 2) post-harvest storage practices, and 3) seasonal influences in relation to these practices. The processes of washing and declumping altered mussel cellular stress compared to unprocessed mussels. However, the process of debyssing substantially increased cellular stress. Mussels held under chilled or iced storage conditions displayed increased cellular stress compared to those held under wet storage. Results of NRA and shelflife trials during the postspawning, prespawning, and recovery periods displayed seasonal patterns in mussel response to stress. The results demonstrated that NRA is a useful index of physiological stress in mussels subjected to conditions under various culture practices.
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The Effects of Environmental Factors, Including Seasonal Changes, on the Fatty Acid Composition of Cultured Mussels (*Mytilus* spp.)

C. H. McKenzie,[1,2] C. C. Parrish[2,3] and R. J. Thompson[2]

A 3-year study to determine the relationship between bivalve growth and food quality was conducted at two bivalve aquaculture sites in Notre Dame Bay, Newfoundland. Experimental mussels were deployed at two locations within each site. Samples were collected monthly over a two-year period. Analyses included phytoplankton population dynamics, mussel growth and lipid content of phytoplankton and harvested mussels. CTD- fluorometer profiles were obtained to determine the environmental characteristics surrounding the experimental mussels. The fatty acid composition of harvested mussels varied seasonally and annually. Omega-3 fatty acid values ranged from 50% of total fatty acids in October 2000 to a low of 24.62% in May 2001. In year two of the study, fatty acid values in the fall were lower than in the previous year. Omega-3 fatty acid values represented only 31% of total fatty acids in October and 39% in November 2001. In 2000 a large dinoflagellate (*Ceratium tripos*) bloom was detected at both experimental sites, contributing over 90% of the phytoplankton biomass. In the following year, there was no large dinoflagellate bloom in the fall. Other factors, including location within the site, temperature and life cycle (spawning) were discussed in relation to fatty acid content in cultured mussels.
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Feeding Behaviour of Blue Mussels (*Mytilus edulis*) Living Within an Atlantic salmon (*Salmo salar*) Aquaculture Site

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Aquaculture has become an important economic activity in the Bay of Fundy, with nearly 100 salmon farms in operation at present. These facilities create organic wastes such as uneaten food and faeces, which can have negative effects on the immediate environment. To help dampen the effects of this nutrification our AquaNet project is modifying typical aquaculture practices by introducing a multi-trophic system in order to maintain the health of coastal waters and potentially increase profits. The primary objective of this experiment is to determine if blue mussels *(Mytilus edulis)* grown at a salmon (*Salmo salar*) farm (Atlantic Silver, Inc., in Passamaquoddy Bay, NB) exhibit any differences in feeding behaviour as compared to mussels grown at a reference site. Mussels are filmed *in situ* using time-lapse videography and the area of the exhalant siphon (ESA) is used as an indication of feeding activity. While the mussels are being filmed, seawater will be analysed for organic and inorganic matter, particle concentration and volume, chlorophyll a concentration, and seston energy content, which will potentially explain the differences in the feeding activity of the mussels at the test and reference sites. Preliminary results have found that particle concentrations at both test and reference sites were always above the minimum threshold for feeding (4×10^3 particles/ml) but never reached inhibitory levels ($> 60 \times 10^3$ particles/ml). There was no difference in the % maximum ESA of mussels at either site (65-70%), however this is due to low particle concentrations (5,000-15,000 particles/ml) and total particle volume (0.5-2.0 mm^3/L) at both sites at time of testing. Organic matter of the seston at the salmon/test site was greater than the reference site (30-97% and 27-67%, respectively), indicating that the salmon farm may provide a better quality food source. Study findings will explain how mussels modify their feeding behaviour when exposed to aquacultural effluents.
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Monitoring of Therapeutants and Phycotoxins in Mussel *(Mytilus edulis)* and Kelp *(Laminaria saccharina)* Cultured in Proximity to Salmon (*Salmo salar*) in an Integrated System

T. Chopin,[(1)] *S. Eddy,*[(2)] *S. Robinson,*[(3)] *K. Haya,*[(3)] *J. L. Martin,*[(3)] *B. MacDonald*[(1)] *and I. Stewart*[(4)]

One component of our AquaNet project, determining the economical and environmental feasibility and benefits of an integrated aquaculture system for salmon (*Salmo salar*), kelp (*Laminaria saccharina*) and blue mussel (*Mytilus edulis*), is concerned with the safety of the products for human consumption. The concern is with the accumulation of chemical therapeutants used in the treatment of diseases in cultured salmon and of phycotoxins produced by harmful algae. Mussels and kelps growing adjacent to salmon cages have been collected periodically since May 2001. During this period the salmon have been treated for bacterial infections and sea lice infestations. Antibiotics (oxytetracyline) and anti-sea lice chemicals (emamectin benzoate and ivermectin) were not detected in any kelps and mussels sampled from the site. Phycotoxins (domoic acid and paralytic shellfish toxins) were not detected in mussels at levels over the regulatory concentrations except in June 2001 and June 2002, with highest detected concentrations of 370 and 165 g STX equiv per 100 g WW, respectively. This correlated with the occurrence in water samples from the site of *Alexandrium fundyense*, the known producer of PSP toxins. After its disappearance, PSP toxins were readily excreted. These results suggest that kelp, mussel and salmon culture at the same site is feasible from a food safety perspective.

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Spatial and Temporal Analysis of Growth, Condition and Gametogenic Cycle of *Mytilus edulis* L. Suspended at Atlantic Salmon (*Salmo salar*) aquaculture sites in Passamaquoddy Bay, Bay of Fundy, Canada.

T. R. Lander,[1,2] S. M. C. Robinson,[1] B. A. MacDonald,[2] and J. D. Martin[1]

Integrated aquaculture, where "extractive" and "fed" species are grown simultaneously, has been proposed as a means for treating the nutrients and particulate wastes from fish cage farming, and represents a good opportunity for product diversification and subsequent economic gains for salmon growers. We are investigating, as part of an AquaNet project team, the possible advantages of nutritional enrichment for the blue mussel (*Mytilus edulis* L.) grown at various distances from salmon cages (0 m, 200 m, 500 m), in Passamaquoddy Bay, NB. At six stations, three 1m replicate socks of 2001 year-class mussels are being monitored year round, at 3-wk intervals for changes in shell length, total weight, meat and shell yields, and reproductive cycle; and are compared to reference and intertidal populations. Water samples, to determine organic and inorganic constituents, are being taken concurrently with mussel samples at each station. Preliminary findings indicate that mussels at the salmon site have 30% higher meat yields than intertidal populations. Particulate loads increase two-fold within the cages, but no significant differences in growth have yet been detected between cage, 200 m, and reference site mussels, suggesting food is not limiting during the spring/summer period. Study findings will provide vital production and reproductive data to set the framework for integrated multitrophic level aquaculture in New Brunswick.

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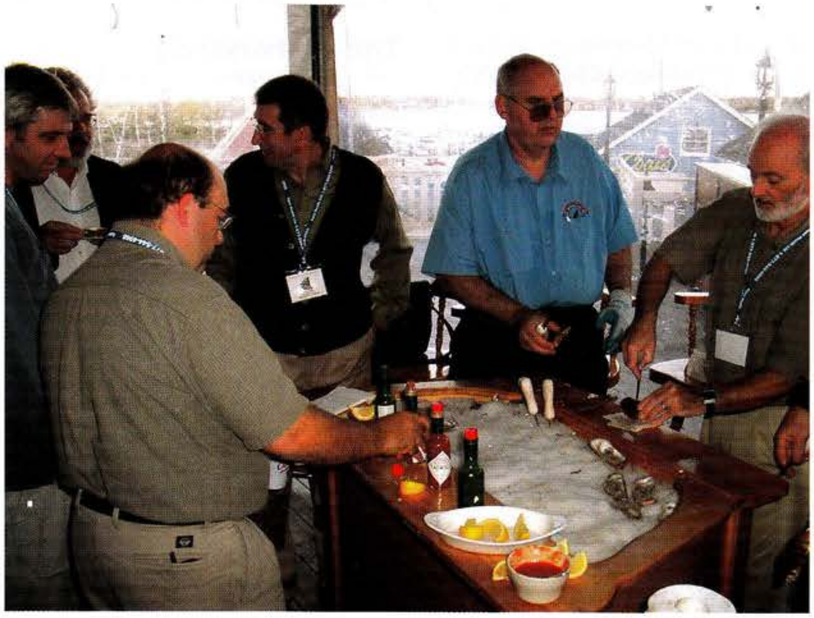

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Introduction

This paper provides an overview of the marine aquaculture industry in Canada based on statistics for the year 2000, the most recent year for which complete statistics are available. The data provided in this paper represent a compilation of those provided by the Canada Department of Fisheries and Oceans, the respective provincial departments responsible for aquaculture, the different provincial aquaculture associations and the Canadian Aquaculture Industry Alliance.

Marine aquaculture operations are established in British Columbia, Québec, New Brunswick, Nova Scotia, Prince Edward Island and Newfoundland. The industry can be divided into three sectors: the dominant finfish sector, the developing shellfish sector, and the often ignored, but quite alive, seaweed sector. An emerging sector, still at the pilot scale, is the development of multitrophic integrated aquaculture (a balanced combination of finfish, shellfish and seaweed).

Considering the finfish and shellfish sectors together, total aquaculture production reached 120,913 tonnes in 2000, with a farmgate value of Cdn$606.109 million, and provided at least 7484 direct and 3476 indirect jobs. The three leading provinces were: British Columbia [56,340 tonnes (46.6%) valued at Cdn$294.8 million (48.6 %)], New Brunswick [30,370 tonnes (25.1%) valued at Cdn$225.525 million (37.2%)], and Prince Edward Island [20,631 tonnes (17.1%) valued at Cdn$28.027 million (4.6%)], accounting for 88.8% of the tonnage and 90.5% of the value of the industry.

Table 1. Canadian finfish aquaculture production and value in 2000.

Province	Species	Production (tonnes)	Farmgate Value (Cdn$ million)	Number of Companies	Number of Licences	Number of Sites	Number of Hatcheries	Number of Jobs
British Columbia	Salmon	49,400	281.700	12	122	104	19	1775 direct 1620 indirect
New Brunswick	Salmon	29,000	223.000	30	87	87	19	1683 direct 1322 indirect
Nova Scotia	Salmon	3425	18.893	45	104	104	18	347 direct
	Steelhead trout	4681	19.395					
Newfoundland	Salmon	670	4.962	68	105	91	9	305 direct
	Steelhead trout	842	5.494					
	Cod	161	0.500					

Table 2. Canadian shellfish aquaculture production and value in 2000.

Province	Species	Production (tonnes)	Farmgate Value (Cdn$ million)	Number of Companies	Number of Licences	Number of Sites	Number of Hatcheries	Number of Jobs
Prince Edward Island	Mussel	17,899	21.703	110	427	284	2	1500 direct
	Oyster	2732	6.324			765		500 indirect
British Columbia	Oyster	5900	7.000	231	417	487	3	800 direct
	Clam	1000	5.900					
	Scallop	40	0.200					
Nova Scotia	Mussel	1252	1.442	63	277	277	4	619 direct
	Oyster	773	1.891					
	Scallop	19	0.162					
	Other	306	1.693					
Newfoundland	Mussel	1051	2.700	57	116	104	0	270 direct
New Brunswick	Mussel	750	0.825	5	515	515	0	125 direct
	Oyster	620	1.700	50				and indirect
Québec	Mussel	339	0.543	23	30	40	1	60 direct
	Other	53	0.082					34 indirect

Finfish Sector

In 2000, the total Canadian finfish production was 88,179 tonnes, valued at Cdn$553.944 million, and provided at least 4110 direct and 2942 indirect jobs (Table 1). This sector is dominated by salmon aquaculture, with a production of 82,495 tonnes (93.6%) and a value of Cdn$528.555 million (95.4%). Salmon aquaculture is predominantly developed in British Columbia [49,400 tonnes (59.9%) valued at Cdn$281.700 million (53.3%)] and in New Brunswick [29,000 tonnes (35.2%) valued at Cdn$223.000 million (42.2%)]. If there is a relatively high number of sites (104 in British Columbia and 87 in New Brunswick), the number of companies operating them is much smaller, especially in British Columbia (12 and 30, respectively), indicating a consolidation of the industry among a few key companies. The salmon industry is providing a total of 3458 direct and 2942 indirect jobs in these two provinces.

Salmon is also cultivated, but in much smaller quantities, in Nova Scotia and in Newfoundland. These two provinces are also involved in the aquaculture of steelhead trout and cod. From the numbers of sites (104 and 91, respectively) and companies (45 and 68, respectively), it is obvious that operations are at a much smaller scale than in British Columbia and New Brunswick and one can anticipate that a certain number of sites are licensed for future development beyond what is presently operational.

Shellfish Sector

In 2000, the total Canadian shellfish production was 32,734 tonnes, valued at Cdn$52.165 million, and provided at least 3374 direct and 534 indirect jobs (Table 2). This sector is dominated by mussel aquaculture with a production of 21,291 tonnes (65.0%) and a value of Cdn$27.213 million (52.2%), followed by oyster aquaculture [10,025 tonnes (30.6%) valued at Cdn$16.915 million (32.4%)]. Prince Edward Island contributes 63.0% of the tonnage of shellfish aquaculture and 53.7% of its value.

Mussel production is predominantly in Atlantic Canada, with 84.1% originating from Prince Edward Island, 5.9% from Nova Scotia, 4.9% from Newfoundland and 3.5% from New Brunswick. On the other hand, oyster production takes place on both the Pacific coast (58.8% in British Columbia) and the Atlantic coast (27.3% in Prince Edward Island, 7.7% in

Nova Scotia and 6.2% in New Brunswick).

Clam aquaculture (3.1% in tonnage and 11.3% in value) is carried out mostly in British Columbia. Scallop aquaculture remains small, with operations in both British Columbia and Nova Scotia (0.2% in tonnage and 0.7% in value). Pilot projects are being carried out on both clam and scallop aquaculture in New Brunswick.

The high number of companies and sites indicates that operations in this sector are generally small and use many sites, some of which are licensed for future development.

Seaweed Sector

The seaweed aquaculture sector is often neglected and ignored in world statistics—a situation we can only explain as being due to a deeply rooted zoological bias in marine academics, resource managers, bureaucrats and policy advisors! It is, however, important to remind the reader that, in 1998, the seaweed industry represented 8.6 million tonnes valued at US$6.2 billion and that 87.1% of this tonnage came from aquaculture valued at US$5.9 billion.[3-5] In the marine environment, 44% of the annual aquaculture production is provided by seaweeds. Worldwide, the top species in annual production (4.17 million tonnes) is the kelp, *Laminaria japonica*, which ranks #3 in annual value (US$2.95 billion); by comparison, Atlantic salmon, *Salmo salar*, does not rank in the top ten species in annual production and ranks #7 for its annual value.[2,4]

Surprisingly, the most known component of the seaweed industry is that of the phycocolloids, the gelling, thickening, emulsifying, binding, stabilizing, clarifying and protecting agents known as carrageenans, alginates and agars. However, this component represents only a minor volume (1.03 million tonnes or 12.0%) and value (US$615 million or 9.9%) of the entire seaweed industry (Table 3). The use of seaweeds as sea-vegetables for direct human consumption is much more significant in tonnage (5.7 million tonnes or 66.3%) and value (US$4.8 billion or 77.4%). Three genera, *Laminaria* (or kombu), *Porphyra* (or nori) and *Undaria* (or wakame) dominate the edible seaweed market.

The phycosupplement industry is an emerging component. Most of the tonnage is used for the manufacturing of soil additives; however, the fertilizer and animal feed markets are comparatively much more lucrative if one considers the much smaller volume of seaweeds they require. The use of seaweeds in the development of pharmaceuticals and nutraceuticals, and as a source of pigments and bioactive compounds is in full expansion. This component is presently difficult to evaluate precisely: the use of 3,000 tonnes of raw material to obtain 600 tonnes of products valued at US$3 million could be an underestimation.

The phycoremediation industry, through the development of integrated aquaculture systems, has existed

Figure 1. Aerial view of Acadian Seaplants unique land-based cultivated seaweed operation in Charlesville, Nova Scotia. Photograph courtesy of Acadian Seaplants Limited.

for centuries, especially in Asian countries, through trial and error and experimentation.[1] Western countries have rediscovered these practices over the last 30 years. There are presently efforts to develop integrated systems (fish/shellfish/seaweed) in Chile, Israel, Canada, the USA and several European countries.[1] It is difficult to give a value to the phycoremediation industry as presently no country has yet implemented guidelines and regulations regarding nutrient discharge into coastal waters.[7] As the "user pays" concept is expected to gain momentum as a tool in integrated coastal management, one should soon be able to put a value to the phycoremediation services of integrated systems for improving water quality and coastal health. Moreover, the conversion of fed aquaculture wastes into the production of salable biomass and biochemicals used in the sea-vegetable, phycocolloid and phycosupplement components should increase the revenues generated by the phycoremediation component.

Gathering information on the seaweed sector in Canada is not an easy undertaking. This does not, however, mean that seaweed aquaculture is non-existent in Canada—on the contrary, there are a few very successful stories! As the number of players is limited, production and marketing information are held very closely. Moreover, as one of the companies, Acadian Seaplants Limited, is the only sizeable commercial seaweed grower outside of Asia, this stance is understandable.

After being a subsidiary of FMC Corporation from the USA, supplying raw material (harvest of natural beds of the red alga, *Chondrus crispus*, or Irish moss) for carrageenan extraction in the 1960s and 1970s, Louis Deveau established Acadian Seaplants Limited (ASL) as a private Canadian company in 1981, with its head office in Dartmouth, Nova Scotia (www.acadianseaplants.com). ASL continues to be a diversified manufacturer of innovative and high quality seaweed products based on the harvesting of natural beds of *Ascophyllum nodosum* (rockweed), *C. crispus*, *Furcellaria lumbricalis* and several species of *Fucus* and *Laminaria*. ASL employs 150 full-time staff, 150 part-time staff and 310 seasonal harvesters. It has 5 manufacturing facilities in Nova Scotia, New Brunswick and Prince Edward Island. Export sales represent 95% of the production, with markets in more than 65 countries where Acadian Seaplants' seaweed products are used for carrageenan extraction, beer clarification, agrichemicals (biostimulants and fertil-

Table 3. Components of the world's seaweed industry. Data from Hanisak 1998, Zemke-White and Ohno 1999, FAO 2000, Chopin et al. 2001, McHugh 2001).

Component of the Seaweed Industry	Raw Material (wet tonnes)	Product (tonnes)	Value (US$)
Sea-vegetable industry	**5.70 million**	**1.15 million**	**4.8 billion**
Kombu *(Laminaria)*	4.2 million	1 million	2.9 billion
Nori *(Porphyra)*	0.9 million	91,000	1.5 billion
Wakame *(Undaria)*	0.5 million	33,000	230 million
Phycocolloid industry	**1.03 million**	**58,500**	**615 million**
Carrageenans	448,000	28,000	270 million
Alginates	460,000	23,000	213 million
Agars	125,000	7,500	132 million
Phycosupplement industry	**1.22 million**	**242,600**	**53 million**
Soil additives	1.10 million	220,000	30 million
Agrichemicals (fertilizers and biostimulants)	20,000	2,000	10 million
Animal feed supplements and ingredients	100,000	20,000	10 million
Pharmaceuticals, nutraceuticals, botanicals, pigments, bioactive compounds, beer brewing, etc.	3,000	600	3 million
Phycoremediation industry	?	?	?

izers), animal feed supplements and ingredients, edible sea-vegetables, nutraceuticals, and botanicals for the health and beauty industries. It is estimated that ASL represents approximately 30 to 40% of the world market of the phycosupplement industry. ASL is also a world leader in the development of a land-based seawater tank cultivation system involving several seaweed strains. Through a very successful collaboration with Dr. James Craigie, from the Institute for Marine Biosciences of the National Research Council of Canada in Halifax, ASL developed a unique 8-hectare commercial cultivation operation in Charlesville, Nova Scotia (Fig. 1), which produces a unique strain of *C. crispus*, Hana-nori™ (Fig. 2), for the Asian (mostly Japanese) human food market (kaiso salads, sashimi garnishes and soups). The transformation of the Charlesville operation from an Irish moss cultivation facility for carrageenans into one for edible seaweeds, with much higher added value, was a remarkable conversion and a brilliant niche market strategy for the company, which plans to cultivate other species. ASL invests approximately 10% of its revenue in resource and product R&D and manufacturing technology annually.

Canadian Kelp Resources Ltd. (CKRL) was established by Dr. Louis Druehl in 1981 at Bamfield on Vancouver Island (www.canadiankelp.com). It is a family owned and operated company (3 full-time employees and a few seasonal workers). It cultivates approximately 5 tonnes per year of brown algae, *Alaria marginata*, *Laminaria saccharina* and *Macrocystis integrifolia*, on a 0.28-ha farm. Kelp seed production can meet the need of two other farms totaling about 0.8 ha. CKRL also harvests 8 tonnes per year from wild beds. The products of CKRL are kelp seeds and sea-vegetables for human consumption (Canadian Kelp Flakes and Barkley Sound Sheet Bull Kelp, Kombu and Macrokelp), pharmaceutical and homeopathic companies (kelp products with a high unsaturated fatty acid profile), health food stores (special kelp blends), cosmetic companies and feeds for abalone and sea urchin cultures. CKRL also offers consulting services on kelp farming, kelp product development and processing, and environmental assessment and bioremediation for the Huu Ay Aht First Nation on Vancouver Island and their herring-roe-on-kelp industry, which is worth Cdn$20 million along the coast of British Columbia and Alaska.

Ocean Produce International (OPI), founded in 1995, can operate a greenhouse with tanks using a saltwater well system in Shelbourne, Nova Scotia (www. oceanproduce.com). The production capacity is reported to be 20-36 tonnes per year. It employs 15-25 people directly and cultivates two dwarf male mutants of the red alga *P. palmata*, named Nova Scotia Sea Parsley™ and opika-1™, respectively. They are used in the following applications: 1) culinary products (dried Sea Parsley Florets™ and Sea Parsley™); 2) nutraceuticals (Green Sea Parsley™ as an ingredient in "green drink" powders, source of omega-3 compounds, and Sea Parsley Capsules™); 3) functional foods and drinks; 4) cosmetics and skin care products (Sea Parsley Antisensitivity Compound™); and 5) fine chemicals (excitatory amino

Figure 2. Mixed salad of Aka Hana-nori (pink), Ao Hana-nori (green) and Kiku Hana-nori (yellow), which are produced from strains of the red alga *Chondrus crispus*. Photograph courtesy of Acadian Seaplants Limited.

acid products opika-1™ kainic and dihydrokainic acids for neurological research).

Conclusion and Future Perspectives

Unconfirmed data for 2001 show a significant increase in aquaculture production, but a marginal increase in value, associated with worldwide financial difficulties (low prices due to oversupply, trade barriers and a declining USA economy) in the salmon aquaculture industry. Further consolidation into the hands of fewer multinational companies can be expected. In 2001, aquaculture production is believed to have reached 141,600 tonnes, with 107,700 tonnes for the finfish sector and 33,900 tonnes for the shellfish sector.

In light of these difficult market conditions, the need for diversification of the Canadian aquaculture industry is imperative to maintain its competitive- ness. Moreover, it is clear that in some regions, like the Bay of Fundy in Southwest New Brunswick, the scope for expansion of monoculture activities is limited. In New Brunswick, salmon aquaculture is geographically highly concentrated within a rectangle of 50 x 40 kilometres in the Quoddy region. After a lengthy process, the number of sites increased in 2001 from 87 to 96. It is anticipated that new sites will be difficult to obtain in the future, and that expansion of appropriate sites outside of this rectangle will be limited. Consequently, the New Brunswick salmon aquaculture industry has to accept that its production will increase only modestly and that inflated predictions would just not be realistic.

It is, therefore, time to realize that monoculture practices do not offer the best use of cultivation units. When one considers the seawater volume available at a leased site and the volume of water column actually occupied by the series of salmon cages, it is obvious that a cultivation unit (*i.e.,* site) is not optimized. Developing integrated aquaculture systems will not only bring increased profitability per cultivation unit through economic diversification of co-cultivating several value-added marine crops, it will also bring environmental and social sustainability and acceptability. Combining fed aquaculture of finfish with extractive organic aquaculture of shellfish, and extractive inorganic aquaculture of seaweed, provides a balanced ecosystem approach to aquaculture and a cost-effective means for reaching effluent regulation compliance by reducing the internalization of the total environmental costs.[1,6]

In collaboration with colleagues at the University of New Brunswick, the Canadian Department of Fisheries and Oceans, and the Canadian Food Inspection Agency, we are presently conducting a project with the support of AquaNet, the Network of Centres of Excellence in Aquaculture in Canada. At an industrial pilot scale site in the Passamaquoddy Bay, provided by Atlantic Silver Inc., salmon (*S. salar*), mussel (*Mytilus edulis*), and kelp (*L. saccharina*) are being grown together to develop an integrated aquaculture model and to train students and professionals in this innovative approach to aquaculture. The productivity and role of each component (fish, shellfish and seaweed) is being analyzed so that the appropriate proportions of each of them can be defined in order to develop a sustainable system in which metabolic processes counter-balance each other within acceptable operational limits and according to food safety guidelines and regulations. The ultimate goal of this project is to transfer this model to other sites and make it a concept transferable to other aquaculture systems.

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New Publications and Websites

Fish and Seafood Products & Services Directory (2002 edition) of the Fisheries Council of Canada. CDN$49 (US$35). The Directory is a reference document listing the products and services provided by the entire Fisheries Council membership. It contains over 175 member firms and detailed profiles of processors and service firms, including key contact names, telephone, facsimile, e-mail and websites. It is also cross-referenced by species and product form and type of business. To order, contact the Fisheries Council of Canada, #110-38 Antares Drive, Ottawa, ON Canada K2E 7V2.

Recreational Fisheries: Ecological, Economic, and Social Evaluation, edited by Tony J Pitcher and Charles Hollingworth, published April 2002 by Iowa State University Press. 288 p., hardcover, ISBN 0-632-06391-2, US$127.99. This book illustrates how the costs and benefits of recreational fishing are evaluated at regional, national, and international levels, using surveys from North America, Australia, South Africa and Europe. Contents include a historical overview of the catch-and-release program, an economic evaluation of recreational fishery policies, maintaining quality in recreational fisheries and other topics of interest. Iowa State University Press. (tel 515 292-0140, fax 515 292-3348, website www.iowastatepress.com).

Fishery Science: The Unique Contributions of Early Life Stages, edited by Lee A Fuiman and Robert G Werner, published September 2002 by Iowa State University Press. 336 p., paperback, ISBN 0-632-05661-4, US$49.99. Each chapter of this book covers topics traditionally taught in fisheries sciences courses, from the view point of the importance of early life stages. It includes topics on population analysis, habitat requirements, fishery management, human impact, case studies and other relevant topics. Iowa State University Press. (tel 515 292-0140, fax 515 292-3348, website www.iowastatepress.com).

Food Safety in Shrimp Processing: A Handbook for Shrimp Processors, Importers, Exporters & Retailers, by Laxman Kanduri and Ronald A Eckhardt, published July 2002 by Iowa State University Press. 180 p., paperback, ISBN 0-852382-70-7, US$129.99. This book explains the Hazard Analysis Critical Control Point (HACCP) process and how to successfully implement it, allows suppliers to the seafood processing industry to optimize their potential sales outlets by facilitating HACCP compliance, and helps shrimp culture and processing businesses to become safer and more efficient through the implementation of HACCP programs. Iowa State University Press. (tel 515 292-0140, fax 515 292-3348, website www.iowastatepress.com).

British Small Animal Veterinary Association's Manual of Ornamental Fish, 2nd edition, edited by William H Wildgoose, published February 2002 by Iowa State University Press. 304 p., illus., paperback, ISBN 0-905214-57-9, $129.99. The topics covered in this book include husbandry and filter systems; diseases by system and cause; practical approach to diagnosis and treatment; details of anesthetic systems and surgery; and information from 29 international contributors. Iowa State University Press. (tel 515 292-0140, fax 515 292-3348, website www.iowastatepress.com).

Biotechnology and Genetics in Fisheries and Aquaculture, by AR Beaumont and K Hoare, published April 2003,by Iowa State Press. 304 p., hardcover, ISBN 0-632-05515-4, US$64.99. This comprehensive but easy to use guide covers major areas such as: the uses of genetic knowledge to captive breeding programs and the use of gene transfer in fish to improve quality, and resistance to disease. This is a must-have guide for fish biologists, fisheries and aquaculture workers, animal geneticists and biotechnologists. Iowa State Press. (tel 515-292-0140, fax 515-292-3348, website www.iowastatepress.com).

Safety and Quality Issues in Fish Processing, edited by H.A. Bremner, published August 2002 by Woodhead Publishing Ltd. 520 p., hardcover ISBN 1-85573-552-0, US$195.00. Book addresses the two central requirements of providing products which are safe and meet the increasing demands for quality. Topics include ensuring safe products, analysing quality and improving quality within the supply

chain. Woodhead Publishing Ltd. (tel +44 0 1223 891358, fax +44 0 1223 893694, e-mail sales@woodhead-publishing.com).

Molluscan Shellfish Farming, by Brian Spencer, published October 2002 by Iowa State Press. 304 p., hardcover, ISBN 0-85238-291X, US$96.99. Provides invaluable commercial information to fish farmers, managers, equipment and feed suppliers, marketing and sales, trading personnel, as well as to libraries and other research establishments where aquaculture is studied or taught. Chapters are devoted to the general biology of bivalves, their predators, hatcheries and each of the major cultured groups: clams, oysters, mussels, scallops and abalone. An important chapter on processing live bivalves for consumption is also included. Iowa State Press (tel 515 292-0140, fax 515 292-3348, website www. iowastatepress.com).

Fishery Science: The Unique Contributions of Early Life Stages, edited by Lee A Fuiman and Robert G Werner, published September 2002 by Iowa State Press. 336 p., paperback ISBN 0-632-05661-4, US$49.99. A complete understanding of the research on the early life history of fishes essential to advanced students of fish biology, fisheries, and aquaculture. Each chapter of the book covers a topic traditionally taught in fisheries science courses, from the point of view of the importance of early life stages. Topics include: population analysis, habitat requirements, fishery management, human impact, case studies and more. Iowa State Press (tel 515 292-0140, fax 515 292-3348, website www.iowastatepress.com).

Ecological Aquaculture: The Evolution of the Blue Revolution, by Barry A Costa-Pierce, published November 2002 by Iowa State Press. 394 p., hardcover ISBN 0-632-04961-8 US$ 109.99. This book covers topics such as: ecological principles and analytical approaches to aquaculture, in-depth analysis of household and village ecosystems and the social ecology of international aquaculture development, detailed discussion of aquaculture farming systems methods used to revise the way aquaculture extension is organized and conducted. Iowa State Press (tel 515 292-0140, fax 515 292-3348, website www.iowastatepress.com).

The latest edition of **Shellfish News** is now available as a .pdf file on the CEFAS website: http://www.cefas.co.uk/publications/shellnews14.pdf. If you have any questions, please contact: Ian Laing (editor), CEFAS Weymouth Laboratory, Barrack Road, The Nothe, Weymouth, Dorset DT4 8UB (tel +44 (0) 1305 206711; fax +44 (0) 1305 206601).

The new website for the Newfoundland Aquaculture Industry Association includes **AQUA NEWS**—Newfoundland and Labrador's Aquaculture Online Magazine (website http://www.naia.nf.net).

Nutrition and Immune Function, edited by PC Calder, CJ Field and HS Gill, published October 2002 by CABI Publishing. 448 p., ISBN 0-85199-5837, US$120. This book provides a review of the roles of specific nutrients in maintaining the immune response and host protection against infection. It also considers the influence of various factors, such as exercise and ageing, on the interaction between nutrition and immune function. The main emphasis is on humans, but comparative mammalian data are also presented. CABI Publishing (tel +44 (0) 1491832111, fax +44 (0) 1491 829292, e-mail orders@cabi.org, website www.cabi-publishing. org/bookshop).

New Species, New Technologies, abstracts of contributions presented at the International Conference Aquaculture Europe 2001. Topics: juvenile and broodstock production, new species, health, nutrition, quality and food safety, production technologies, integrated aquaculture, environment and nutrient loading management, communication, information, funding and networking. EAS Special Publication 29, XIV+286 p., EUR 55 per copy. European Aquaculture Society (tel +32 59 32 38 59, fax +32 59 32 10 05, e-mail eas@aquaculture. cc).

Better Use of Water, Nutrients and Space, handbook of the International Workshop, Trondheim, Norway, 7 August, 2001, comprising contributions and extended abstracts. Workshop Handbook, A4 format, VI+62 p., EUR 35,00 per copy. European Aquaculture Society (tel +32 59 32 38 59, fax +32 59 32 10 05, e-mail eas@aquaculture.cc).

Larvi 2001—Proceedings of the Fish and Shellfish Lariculture Symposium, edited by CI Hendry, G Van Stappen, M Wille and P Sorgeloos. This book, CD-ROM version included, contains the mini-papers of the poster contributions and the abstracts of the oral papers. EAS Special Publication No.30, 2001, soft cover, XXI+663 p. + CD-ROM, EUR 70 for EAS/WAS member, EUR 84 for non-members. European Aquaculture Society (tel +32 59 32 38 59, fax +32 59 32 10 05, e-mail eas@aquaculture.cc).

Calendar

conferences, workshops, courses and trade shows

- **Microalgae and Live Feeds Culture Course**, 8-9 May 2003, Harbour Branch Oceanographic Institution/ACTED, Ft. Pierce, FL, USA. For more information, visit www.aquaculture-online. org or e-mail acted@hboi.edu.

- **World Aquaculture 2003**, 19-23 May 2003, Bahia Convention Center, Salvador, Brazil. Theme: "Realising the Potential: Responsible Aquaculture for a Secure Future". Annual meeting of the World Aquaculture Society held in conjunction with other associations, industry and government sponsors. Information: Director of Conferences (tel 760 432-4270, fax 760 432-4275, e-mail worldaqua@aol.com).

- **Recirculating Aquaculture Systems Course**, 2-6 June 2003, Harbour Branch Oceanographic Institution/ACTED, Ft. Pierce, FL, USA. For more information, visit www.aquaculture-online. org or e-mail acted@hboi.edu.

- **World Summit on Salmon,** 10-13 June 2003, Morris J. Wosk Centre for Dialogue, Simon Fraser, University. Sessions: Taking stock of world fisheries and habitat, State of salmon stocks and habitat, Threats to wild salmon, Solutions for wild salmon conservation, etc. Information: Secretariat, Continuing Studies, Simon Fraser University, Burnaby, BC (tel 604 291-4893, fax 604 291-3851, e-mail penikett@sfu.ca, website www.sfu.ca/cstudies/science/salmon.htm).

- **Atlantic Aquaculture Exposition, Conference and Fair,** 11-15 June 2003. W.C. O'Neill Arena Complex, St. Andrews-by-the-Sea, NB. Theme: *Aquaculture: A Fresh Perspective.* Focus is on issues such as flesh quality, maturation, smolt technology and product traceability. For conference information contact Betty Lord tel 506 529-4578, fax 506 529-4284, e-mail aquafair @nbnet.nb.ca, www. aquafair.ca. For trade show information, contact Sydney Peacock (tel 1 888 454-7469, tel 506 658-0018, toll free 1 888-454-7469, fax 506 658-0750, speacock@ masterpromotions.ca).

- **3rd International Percid Fish Symposium**, 20-24 July 2003, Monona Terrace Convention Center, Madison, WI, USA. Topics: current status of percid fisheries (including a special session on the Great Lakes), management of percid fisheries, recent breakthroughs in aquaculture, and percid biology. For information, contact T.P. Barry (tel 608 263-2087, e-mail tpbarry@ facstaff.wisc.edu).

- **Techniques for the Culture of Finfish Course,** 4-8 August 2003, Harbour Branch Oceanographic Institution, Ft. Pierce, FL, USA. For more information, visit the website www. aquaculture-online.org or e-mail acted@ hboi.edu.

- **Aquaculture Symposium at the 133rd Annual Meeting of the American Fisheries Society,** 10-14 August 2003, Quebec City, Quebec, Canada. Aquaculture Symposium with sessions on 1) Aquaculture: A Pathway to Revitalization for Coastal Communities, 2) Technology and Challenges to Aquaculture Development in Cold Climates, and 3) Interaction between Aquaculture and the Environment. For information, contact: Betsy Fritz (tel 301 897-8616 ext. 212, e-mail bfritz@fisheries.org). Further details are available on the website at http:// www.fapaq.gouv. qc.ca/en/AFS_congres/index_A.htm

- **Aquaculture Europe 2003,** 8-12 August 2003, Trondheim, Norway. Theme: "Beyond Monoculture". Plenary sessions: Economic benefits of integrated aquaculture, Suitability of integrated systems for different regions, Food safety and quality management, Health management, Legislation and regulation, and Key research needs. For more information, contact the European Aquaculture Society (tel +32 59 323859, fax +32 59 321005, e-mail ae2003@aquaculture.cc, website http://www. easonline.org).

- **AquaNor 2003**, 12-15 August 2003, Trondheim Norway. This trade show is being held following the Aquaculture Europe 2003 conference.

For information, contact The Nor-Fishing Foundation (tel +47 73 568640, fax +47 73568641, e-mail mailbox@ nor-fishing.no).

- **Workshop on Mussel Farming Technologies and Development**, hosted by the European Aquaculture Society, 12 August 2003, Trondheim, Norway. A 1-day workshop in conjunction with AquaNor. Information available from the EAS website: http://www.easonline.org.

- **Cold Water Aquaculture in the XXI Century,** 8-13 September 2003, Russia. Language: English and Russia. Topics: ecology, physiology, genetics, artificial reproduction, bioengineering of breeding, etc. Seminars: Start feeds for fish and invertebrates, Problems on reproduction of salmon and white-fish resources, Round-table discussion on perspective development of cold water aquaculture in Russia and the world. The symposium will take place onboard a ship (route is St. Petersburg, Kiji, Pertozavodsk, Valaam, St. Petersburg). Information: Symposium Secretariat, Russian Federal Center of Fish, Genetics and Selection, tel/fax +7 (095) 209 04 45, e-mail fsgcr@ipc.ru, website http//:www.fsgcr.boom.ru.

- **6th International Symposium on Fish Parasites**, 22-26 September 2003, Bloemfontein, South Africa. Information: Prof. Jo Van As, Dept. of Zoology and Entomology, University of the Free State, South Africa (fax +2751 448 8711, e-mail vanasjg@sci.uovs.ac.za).

- **Acquacoltura International**, 15-17 October 2003, Verona, Italy. Contact: Sue Hill (+44 020 7017 4529, fax +44 020 7017 4537, e-mail sue.hill@informa.com, website www. heighwayevents.com).

- **AquaNet III,** 22-25 October 2003, Hyatt Regency Hotel, Vancouver. Information, tel 709 737-3245, e-mail info@aquanet.ca.

- **Aquaculture Canada^{OM} 2003 and Aquaculture and Pacific Exchange Conference and Exhibition,** 29 Oct – 1 Nov 2003, Victoria Conference Centre, Victoria, BC, Canada. For information, contact Linda Heimstra (e-mail heimstra @mala.bc.ca) or the AAC office (aac @mar.dfo-mpo.gc. ca). For trade show information, contact Sydney Peacock at Master Promotions Ltd., (tel 506 658-0018, fax 506 658-0750, e-mail show@ nbnet.nb.ca).

- **3rd International Engineering Society Issues Forum,** 3-5 November 2003, Doubletree Hotel Airport Convention Center, Seattle, Washington. Major topics will be: design of shellfish hatcheries, marine biosecure facilities, flow-through salmon and trout facilities, marine netpens, large-scale laboratory research systems, and cold water re-use systems. To submit papers contact John Colt (tel 206 860-3243, fax 206 860-3467, e-mail john.colt@noaa/gov).

- **Genetics in Aquaculture** VIII, 9-15 November 2003, Puerto Varas, Chile. Triennial symposium celebrating the 21st anniversary of the International Association for Genetics in Aquaculture. For details contact Dr. Roberto Neira (fax +56 2 541 3380, e-mail genaqua@uchile.cl, website www.genaqua.uchile.cl).

- **Aquaculture Australia,** 3-5 December 2003, Sydney Convention & Exhibition Centre, Sydney, Australia. For further details, contact Sue Hill, Exhibition Sales Manager, Heighway Events, Telephone House, 69-77 Paul Street, London, EC2A 4LQ, UK (tel +44 (0)20 7017 4516/4537, e-mail sue.hill@informa.com).

- **Aquaculture 2004**, 1-5 March 2004, Hawaii Convention Center, Honolulu, HI, USA. Triennial meeting of the World Aquaculture Society, the National Shellfisheries Association, and the Fish Culture Section of the American Fisheries Society. Information: Director of Conferences (tel 760 432 4270, fax 760 432 4275, e-mail worldaqua@ aol.com, website www.was.org).

- **Fourth World Fisheries Congress**, 2-6 May 2004, Vancouver, BC, Canada. For information: contact Gary Carmichael (tel 604 688-9655, fax 604 685-3521, e-mail fish2004@advance-group.com or carmichael_gary@yahoo.com, website www.worldfisheries2004.org.

- **2004 Aquaculture Pacific Exchange Conference and Exhibition,** Campbell River, BC, Canada. October 2004. Consists of a 100-booth trade show and 2-day conference. Produced by Master Promotions Ltd., PO Box 565, Saint John, NB (tel 506 658-0018, fax 506 658-0750, e-mail show@nbnet.nb.ca).