Bulletin

of the Aquaculture Association of Canada

Bivalve Hatcheries
Toxic Phytoplankton

Edition 97-3
September, 1997

MARINE INSTITUTE

AQUACULTURE

The Fisheries and Marine Institute of Memorial University offers a Master of Science, Advanced Diploma and Technical Certificate in Aquaculture. Faculty and staff provide industrial assistance, technology transfer, research and extension services to the Canadian and international aquaculture industry.

Master of Science (Aquaculture)

The only thesis-based M.Sc. in aquaculture in Canada. Aquaculture research on:

- biology
- ecology
- biochemistry
- production
- engineering
- business

Advanced Diploma

This post graduate one-year program is practical-oriented and designed to provide students from a wide range of academic disciplines with the education, training and management level skills required to participate in aquaculture development. The main goals are to provide:

- training for employment in a variety of aquaculture vocations
- management level training for aquaculture industries.

Technical Certificate

Program developed in response to requests for salmonid, shellfish, and marine finfish aquaculture training from existing and prospective farmers and government agencies. Designed to provide skills:

- to establish a farm site
- to obtain employment at farm sites
- to communicate in business
- to develop a business plan

Industrial Assistance and Research

Highly skilled faculty and staff provide assistance to industry in: fish nutrition, fish health, shellfish production, equipment development, site selection and monitoring, and data analysis. Researchers are also actively involved in the development of new species for aquaculture including: charr, wolffish, sea urchin, giant scallop and cod.

Training programs and industrial assistance services offered by the Marine Institute have access to state-of-the-art teaching and research facilities available throughout Memorial University and St. John's. Both teaching and research activities in aquaculture are strengthened by strong working links with industry and the Ocean Sciences Centre.

For more information on Industrial Assistance, Research and programs contact:
School of Fisheries, Marine Institute
P.O. Box 4920
St. John's, NF Canada A1C 5R3
Tel: 1-800-563-5799 Fax: (709) 778-0535
www.ifmt.nf.ca

For more information on the Master of Science program contact:
School of Graduate Studies
Memorial University of Newfoundland
St. John's, NF Canada A1B 3X5
Tel: (709) 737-8200
Fax: (709) 737-3421

Memorial
University of Newfoundland

Bulletin of the Aquaculture Association of Canada

The *Bulletin* is available through subscription ($40. per year) or as a benefit of membership in the Aquaculture Association of Canada, a nonprofit charitable organization. For membership information contact: Aquaculture Association of Canada, P.O. Box 1987, St. Andrews, N.B., Canada EOG 2X0 [telephone 506 529-4766; fax 506 529-4609; e-mail aac@wolves.sta.dfo.ca; web site http://www.ifmt.nf. ca/mi/aac]. Annual dues are $40 for students and seniors, $50 for individuals, and $85 for companies; 25 percent of dues is designated for *Bulletin* subscription.

The Bulletin is abstracted and indexed in Aquatic Sciences and Fisheries Abstracts (ASFA). Mailed under Canada Post Publications Mail Product Sales Agreement No. 525375. Change of address notices and undelivered copies should be mailed to AAC. Return postage guaranteed.

Officers
Jay Parsons, President
Yves Bastein, President-Elect
Joseph Brown, Past-President
Andrew Boghen, Vice-President
Julian Hynes, Secretary
Shawn Robinson, Treasurer

Directors
Ted White
Diane Morrison
John Holder

Bulletin Staff
Susan Waddy, Editor
Dave Aiken, Jay Parsons, Andrew Boghen, Contributing Editors

ISSN 0840-5417
Printed by McCurdy Printing Ltd., Sackville, N.B.

Cover:

Stages in the sexual reproduction of the pennate diatoms *Pseudo-nitzschia pseudodelicatissima* (isolated from the Black Sea) and *Pseudo-nitzschia multiseries* (isolated from Cardigan Bay, Prince Edward Island). The latter species is a producer of the neurotoxin domoic acid that contaminated cultivated blue mussels in eastern Canada in 1987. Blooms of this diatom have since subsided, and no toxic events have occurred recently (see article starting on page 9).

Diatom cells become smaller each time they divide vegetatively, because they are constructed of a rigid frustule made of silicon. Eventually the small cells would die, were it not for their ability to carry out sexual reproduction in order to regain the largest cell size. Sexual reproduction starts with "male" and "female" cells forming a pair, either as individual pairs or as a single cell pairing with another in a chain of cells (top photo). Each cell in the pair produces two round gametes that fuse with the gametes in the adjacent cell, forming two larger round zygotes (middle cells of top and second to top photo). The zygotes then become auxospores, which continue to elongate to a maximum size (third photo from top, and photo at right). A large initial cell then forms within the fully expanded auxospore (fourth photo from the top). Once the initial cell exits from the auxospore, it starts to divide vegetatively, forming the characteristic chain of Pseudo-nitzschia cells with overlapping tips (bottom photo). This process is described by Davidovich and Bates (1998, *Journal of Phycology* 34: 126-137). An understanding of the timing of sexual reproduction may provide some insights into the timing of toxic *Pseudo-nitzschia* blooms in the field. Recent results show that large initial cells are highly toxic compared to the small parent cells which have virtually lost their ability to produce domoic acid. Scale bars = 100 μm. (Photos by Nickolai A. Davidovich and Stephen S. Bates).

Aquaculture Canada '97

Organizing Committee / Comité organisateur

Chairman / Président	Yves Bastien
President of AAC / Président de l'AAC	Joe Brown
Program coordination / Coordination du programme	Yves Bastien, Bruno Myrand
Scientific Program / Programme de conférences	
Salt water / Eaux salées	Bruno Myrand
Fresh water / Eaux douces	Pierre Dubé
Technical sessions / Sessions techniques	Tom Sephton, Andrée Leblanc
Special sessions / Sessions spéciales	Bruno Myrand, Pierre Dubé Joe Brown, Éric Gilbert, Cynthia McKenzie Roberta Lavigne, Maureen McInerney-Northcott, André Mallet Sharon Ford, Yves Boulanger, J. de la Noüe
Social activities / Programme d'activités sociales	Yves Bastien, Jean-Yves Savaria Diane Tremblay
Trade show / Salon commercial	Michel Larrivée
Registration / Inscription	Maureen McInerney-Northcott
Audio-visual and simultaneous translation / Audio-visuel et traduction simultanée	André Dubois, Yves Bastien Céline Major
Student activities / Activités étudiantes	Jean-Yves Savaria Maureen McInerney-Northcott
Publicity and promotion / Publicité et Promotion	Yves Bastien, Linda Anctil Maureen McInerney-Northcott
Site tours / Visites organisées	Grant Vandenberg
Media relations / Relation avec les médias	Linda Anctil
Treasurer / Trésorier	Tillmann Benfey
Photography / Photographe	Michel Desbiens
Other members of the organizing committee / Autres membres du comité d'organisation	Sylvain Vigneau, Jean-Pierre Réville Lucien Maheux, Michel Bombardier

Contents

Bulletin of the Aquaculture Association of Canada 97-3
S. L. Waddy and M. Frechette, editors

Aquaculture Canada '97

We gratefully acknowledge the following supporters and sponsors
Nous remercions sincèrement tous nos supporteurs et commanditaires

Financial suppporters / Supporteurs financiers

Department of Fisheries and Oceans (DFO) / Ministère des Pêches et des Océans (MPO)

Société de Recherche et Développement en Aquiculture Continentale (SORDAC)

Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec (MAPAQ)

Canadian Center for Fisheries Innovation (CCFI)

Association des Aquiculteurs du Québec (AAQ)

Marinard Aquaculture Ltée.

GRT Aqua-Technologies Ltée.

Natural Sciences and Engineering Research Council (NSERC)/ Conseil de recherches en sciences naturelles et génie (CRSNG)

National Research Council (NRC-IRAP) / Conseil National de la Recherche (CNR-PARI)

Sponsors / Commanditaires

Hydro-Québec — Direction régionale réseau autonome

Société de développement de l'industrie maricole (SODIM)

Atlantic Provinces Council on the Sciences(APICS)

Association des Aquiculteurs du Québec (AAQ)

University of Guelph Aquaculture Centre

Northern Aquaculture

Contact Canada

Bureau Fédéral de Développement Régional (Québec)

Office of Regional Development (Québec)

Centre Spécialisé des Pêches (Cégep Gaspésie et les Îles)

Les Consultants Filion, Hansen & Ass. Inc.

Moore-Clark Co. (Canada) Inc.

Heritage Salmon

Donat Bilodeau Experts Conseils Inc.

Instruments Anateck

Restaurant Le Lapin Sauté

Andrew Boghen

Claude Levasseur

Organizational assistance / Organismes qui ont contribué à l'organisation

MAPAQ

Centre Spécialisé des Pêches (Cégep Gaspésie et les Îles)

Canadian Aquaculture Industry Alliance (CAIA) / Alliance de l'Industrie Canadienne de l'Aquiculture

SORDAC

Office du tourisme et des congrès de la Communauté urbaine de Québec

Université Laval

Pisciculture des Alléghanys

Station piscicole de Tadoussac

DFO / MPO

Donnors of seafood and aquaculture products / Donateurs de produits d'aquaculture et marins

Coopérative Aquicole du Québec

Viamer Inc.

Les moules de culture des Îles Inc .

Pêcheries Gros-Cap Inc.

Poséidon Inc.

Text of the speech given by Mr. Louis Tousignant, Senior Assistant Deputy Minister, Department of Fisheries and Oceans, at Aquaculture Canada '98

Je voudrais d'abord remercier l'exécutif de l'AAC pour avoir invité le sous-ministre des Pêches et des Océans, M. Bill Rowat, à prendre la parole devant les membres de l'association. Malheureusement, M. Rowat avait déjà un engagement et il m'a demandé de le remplacer ici aujourd'hui.

On m'a dit que l'association tenait sa 14ième assemblée annuelle et que bon nombre d'entre vous oeuvrent au sein de l'AAC depuis sa fondation. Qui d'autre que vous serait mieux placé pour savoir tout le chemin parcouru par cette industrie en si peu de temps:

- Une production de 7 millions de dollars en 1984;
- Puis de 343 millions de dollars en 1995, soit 49 fois plus en dix ans seulement;

L'industrie, aujourd'hui, se trouve à un carrefour critique dans son développement elle est confrontée à la fois à la nécessité de prendre de l'expansion et à celle de mieux performer sur le plan des frais d'exploitation afin de devenir plus concurrentielle sur les marchés internationaux.

And, in reality, competition for markets or "stomach space" is not simply with other aquaculture-producing nations, but with food producers everywhere.

The greatest challenge, and achievement, may lie in convincing consumers of beef, pork, chicken and turkey to eat farmed seafood.

Mr. Louis Tousignant addressing the opening session of Aquaculture Canada '98.

To that end, I feel that the theme of this year's meeting "From Research to Marketing" has hit the mark.

As I am sure all of you are aware, the federal government's role in aquaculture has evolved, in part, due to tremendous industry growth and in part to public sector efforts to restructure and "right-size". The federal government's role is evolving from a primary funding source to more of an advocate and facilitator. Throughout this process, DFO has attempted to coördinate this evolution at the federal level.

In the recent past, the Government of Canada has listened very closely to the concerns of industry. All of you are aware of last year's efforts by the Liberal Caucus Task Force on Aquaculture. Some of you no doubt have had an opportunity to provide the task force with your views on how to unlock the considerable economic potential that resides in the aquaculture sector.

In the Liberal Party's 1997 election platform, the Prime Minister has responded positively to the industry's input to the task force by committing to appoint a Commissioner for Aquaculture Development reporting to the Minister of Fisheries and Oceans.

While it is too early to be very specific about the commissioner's position, the commissioner's primary mandate, as set out in "Red Book 2", would be to foster renewed industry growth generally.

To the extent that "Red Book 2" mentions how the commissioner would go about this primary task (and the Red Book doesn't provide detailed information), I am encouraged to note that everything that is specified seems consistent with the Federal Aquaculture Development Strategy announced by the Minister of Fisheries and Oceans in 1995. In particular, the Commissioner for Aquaculture Development would be expected to:

- Promote investment in R&D;
- Assure access to growing sites;
- Lead required regulatory reform;
- Integrate supportive federal resources;
- Work with the provinces; and
- Develop a vibrant, environmentally sensitive industry.

En fait, je dirais que l'on pourrait s'attendre d'un commissaire qu'il se fasse le défenseur de l'industrie au sein du gouvernement.

C'est un pas dans la bonne direction et aussi une preuve que nous tenons compte de vos opinions.

Comme vous le savez sans doute, dans la mise en oeuvre de la stratégie fédérale de développement de l'aquaculture, le MPO a travaillé en étroite collaboration au cours de la dernière année avec l'Alliance de l'Industrie Canadienne de l'aquiculture afin:

- D'identifier et d'abattre les principaux obstacles réglementaires fédéraux qui nuisent à la croissance et à la compétitivité de l'industrie; et
- D'identifier les autres facteurs qui nuisent au succès de l'industrie, en employant des outils comme le test de l'impact sur les entreprises (TIE) élaboré en collaboration avec l'Association Canadienne des Manufacturiers, le Secrétariat du Conseil du Trésor et Industrie Canada.

La plupart d'entre vous êtes sans doute déjà au courant des détails des différentes réformes de réglementation et de politiques qui sont soit achevées, soit en cours — abolition des restrictions quant à la taille minimale des palourdes japonaises et des huîtres abolition des exigences d'étiquetage pour le saumon atlantique d'élevage, protocoles de *L'Organisation pour la Conservation du Saumon de l'Atlantique Nord* (OCSAN), amélioration de l'accès aux ressources sauvages — je ne vais donc pas m'éterniser sur le sujet.

Cependant, je tiens à vous assurer que je sais très bien les frustrations qu'éprouve l'industrie devant le temps qu'il faut au gouvernement pour opérer ces changements.

The reality is that DFO is committed to the **PRECAUTIONARY PRINCIPLE** in the management of fishery and ocean resources. As you probably know, this means that if we are not sure about the effect of a proposed activity, then we should act carefully.

Moreover, we have a responsibility to consider the views of all user groups when changes to policy or regulations are proposed. The consultation process is a time-consuming but necessary step.

This does not mean that DFO is pushing for zero-risk aquaculture operations. It is definitely not, although I am sure that many in the industry would argue that DFO has been overly risk-averse in its approach in the past.

The key idea is balancing economic and environmental objectives. This is what sustainability is all about and I expect that a new commissioner would bring this perspective forcefully to the table, in all discussions about aquaculture development.

Bon nombre de représentants de l'industrie ont aussi fait valoir, directement au MPO et aussi devant le groupe de travail, que le rôle du MPO comme organisme de réglementation de l'industrie est souvent entré en conflit avec des tentatives d'agir en tant que défenseur des intérêts de l'industrie.

En sa qualité de défenseur des intérêts de l'industrie, je serais porté à croire qu'un nouveau Commissaire au Développement de l'Aquaculture serait bien placé pour résoudre ce conflit apparent en constituant un contrepoids efficace au rôle d'organisme de réglementation.

Même si je pense que la nomination d'un commissaire aiderait à préciser les rôles, le message que je suis venu vous porter ici aujourd'hui, c'est qu'il est important que nous travaillions ensemble pour parvenir à une approche équilibrée. Le gouvernement fédéral, le MPO en particulier, est à l'écoute, mais nous devrons travailler en concertation pour produire des résultats.

In my view, it is the industry's job to continue to produce and market the finest cultured products the world has to offer, and, I might add, at the best price. It is also critical that industry invest in the R&D required to commercialize new species.

For our part, we will continue to support R&D to the extent we can, and to concentrate on those areas that will facilitate industry growth.

And, in ten years' time, if members of the aquaculture industry can make the frank admission that the federal government:

- Really listened to industry's views on what was required;
- Acted where it had the authority and competence to do so;
- Refrained from meddling where it wasn't called for;
- Turned the talks into tangible results;
- Helped industry to be more cost-competitive;
- Helped industry to diversify into new and profitable species and product lines;
- And helped industry, overall, to achieve its vision

...Then we will have played a valuable and appropriate role.

It has been a pleasure to speak to you today. I trust that we will all come away from this meeting buoyed up to face the challenges ahead.

Aquaculture Canada '99

annual meeting of the Aquaculture Association of Canada
27 – 29 October 1999
Victoria Convention Center, Victoria, British Columbia

Information: Linda Townsend
fax 250 755-8749,
e-mail townsdl@mala.bc.ca

Aquaculture Canada '97

List of Exhibitors / Liste des Exposants

ALPHA MACH
Beloeil, Québec

AQUABIOTECH INC.
Coaticook, Québec

AQUIPRO
St-Apoillinaire, Québec

ASSOCIATION DES BIOLOGISTES DU QUÉBEC (ABQ)
Montréal, Québec

ATLANTIC FISH FARMING
Montaque, Prince Edward Island

CONTACT CANADA
Canadian Aquaculture Directory
Georgetown, Ontario

CANADIAN AQUACULTURE INDUSTRY ALLIANCE (CAIA)
Ottawa, Ontario

CANADIAN CENTRE FOR FISHERIES INNOVATION (CCFI)
St. John's, Newfoundland

CENTRE SPÉCIALISÉ DES PÊCHES
Grande-Rivière, Québec

COMMISSION SCOLAIRE MIGUASHA
Carleton, Québec

DANOVAR
Victoriaville, Québec

FUTURE SEA FARMS, INC.
Nanaimo, B.C.

INSTRUMENTS ANATECK
Gatineau, Québec

LARSA ((LABORATOIRE RÉGIONAL DES SCIENCES AQUATIQUES)
Ste-Foy, Québec

LES FORARAGES L.B.M. INC.
Victoriaville, Québec

MINISTÉRE DE L'AGRICULTURE DE PÊCHERIES ET DE L'ALIMENTATION DU QUÉBEC (MAPA)
Gaspé, Québec

NATIONAL RESEARCH COUNCIL
Institute for Marine Biosciences (IMB)
Halifax, Nova Scotia

NORTHERN AQUACULTURE
Courtenay, British Columbia

PISCES INDUSTRIES LTD.
Wells, Michigan

POMPES INDUSTRIELLES STE-FOY
Ste-Foy, Québec

SCIENCE IMPORT
Québec, Québec

ST-JEAN FILTRATION (1987) INC.
St-Jean-sur-Richelieu, Québec

Toxic phytoplankton on the Canadian east coast: Implications for aquaculture

Stephen S. Bates

The east coast of Canada is impacted by harmful algal bloom (HAB)-forming phytoplankton that are an impediment to aquaculture and shellfish harvesting in general. Toxic phytoplankton include: 1) paralytic shellfish poison (PSP)-producing *Alexandrium fundyense* in the Bay of Fundy, and *A. tamarense* and *A. ostenfeldii* in the Gulf of St. Lawrence and in Newfoundland; 2) amnesic shellfish poison (ASP; domoic acid)-producing *Pseudo-nitzschia multiseries* in eastern and northern Prince Edward Island, *P. pseudodelicatissima* in the Bay of Fundy, and unknown source(s) on the south shore of Nova Scotia, Georges/Browns Banks, and in Newfoundland; and 3) diarrhetic shellfish poison (DSP)-producing *Prorocentrum lima*, as well as other possible unidentified sources, in southern Nova Scotia, the Bay of Fundy, southern Gulf of St. Lawrence, and eastern Newfoundland. Inexplicably, and fortunately for the shellfish aquaculture industry, all east coast *Dinophysis* spp. have thus far been found without accompanying DSP toxicity. As a result of research and monitoring efforts aquaculturists have been able to cope, for the most part, with the presence of HABs. However, we must guard against complacency during years that HABs appear to be on the decline, because there are long-term cycles in bloom activity and severity. Decreases in federal monitoring of toxic phytoplankton have been offset in part by provincial and industry-funded programs. An increase in partnering is required among federal and provincial agencies, and private industry in order to enhance toxic phytoplankton monitoring and research programs in Canada.

Introduction

The east coast of Canada, as elsewhere in the world, is impacted by the presence of toxic phytoplankton (algae) which produce phycotoxins (algal toxins) that may contaminate molluscan shellfish that feed upon them (Table 1). These algae do not necessarily form "red tides", which are dense concentrations of algae that discolor the seawater. They are often invisible from the surface, but even at low concentrations their presence is cause for concern. Some algal species do not produce toxins, but cause harm due to the accumulation of their biomass (causing oxygen depletion) or to the physical disruption of fish gill tissue by barbed spines. The international scientific community now employs the term "harmful algal bloom" (HAB) to refer to the diverse problems caused by toxic and harmful algae.

The phenomenon of HABs is believed by some scientists to be increasing in frequency, intensity, duration, and geographic extent around the world.[1,2] It is debated whether this is a result of general climatological changes, ship ballast water exchange, anthropogenic eutrophication, increased use of coastal resources, or simply because monitoring efforts have recently expanded. Whatever the cause, the presence of these algae can have a great impact on human health, health costs,[3,4] and on finfish and molluscan shellfish aquaculture.[5] The closure of aquaculture harvesting sites due to HABs results in the obvious immediate loss of revenue because of the curtailment of sales. However, negative publicity from the media may have a longer-lasting impact on consumer confidence, resulting in a decreased demand for non-affected and unrelated seafood products.[6] Aquaculturists can benefit by gaining a greater understanding of HAB-forming species and phycotoxins present in waters of eastern Canada and by taking measures to minimize their negative impacts.

Paralytic Shellfish Poisoning (PSP) Toxins

The PSP toxins are composed of several derivatives of saxitoxin, including gonyautoxins, neosaxitoxin, and N-sulfocarbamoyl and decarbamoyl toxins, which differ in their level of toxicity. Less toxic forms may be converted to more potent ones during chemical extraction, prolonged storage, and also by molluscan shellfish themselves. Temporary closures of shellfish harvesting are initiated when samples exceed the regulatory action limit of 80 µg STXeq 100 g^{-1} tissue.

Shellfish harvesting and aquaculture along the Atlantic coast of Canada (Fig. 1) have been affected by PSP outbreaks for decades.[7] In the Bay of Fundy, molluscan shellfish toxicity has been monitored since 1943 and is the longest time series of this kind in the world.[8] Although there are no definite cycles in toxicity, periods of higher shellfish toxicity may coincide with an 18.6-year lunar tidal cycle. Maintaining

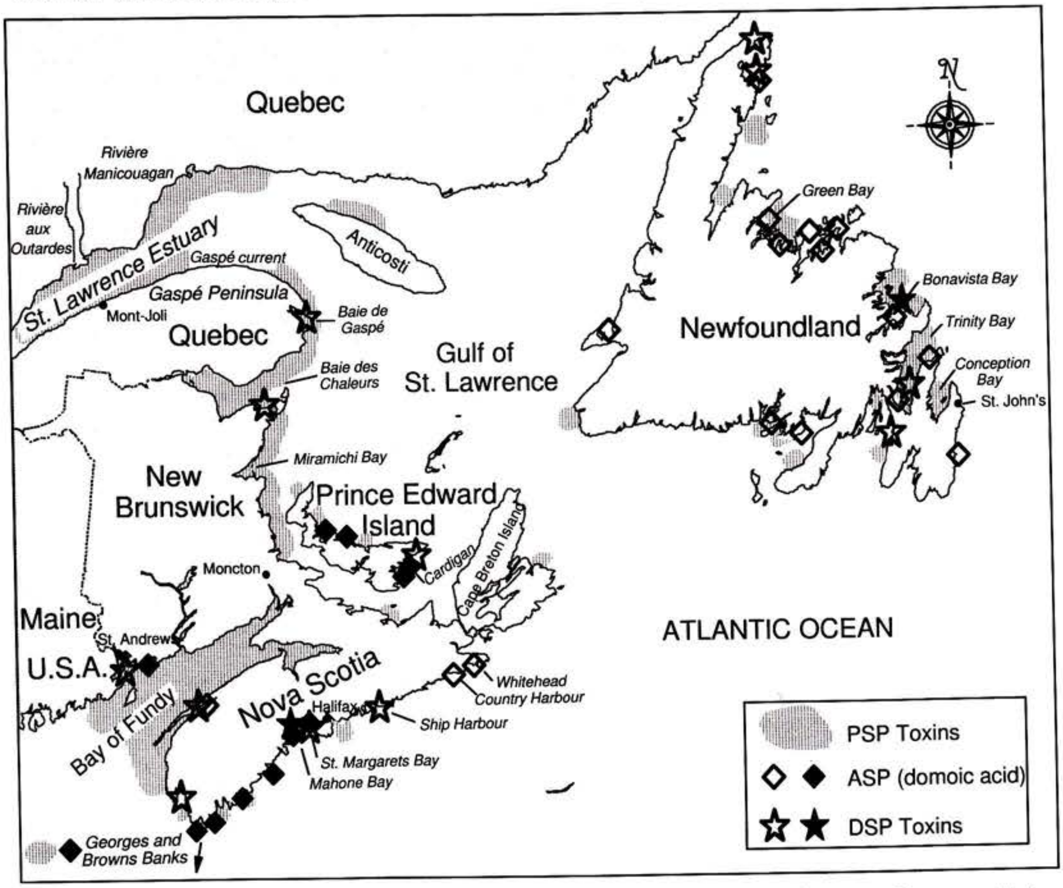


Fig. 1. Location of phycotoxins (PSP, ASP, DSP) along the Canadian Atlantic coast. Open symbols: phycotoxin detected in molluscan shellfish tissue; closed symbols: shellfish harvesting areas closed due to levels exceeding the regulatory action level. Locations shown for PSP toxins (shaded areas) are for levels exceeding the detection limit of the assay; the Bay of Fundy is permanently closed to mussel harvesting, as are four areas in Newfoundland.

Table 1. Phycotoxins and toxic or harmful phytoplankton in eastern Canadian waters.

Phycotoxins	Responsible Organisms
Paralytic shellfish poisoning toxins (saxitoxin derivatives, e.g., gonyautoxin, neosaxitoxin)	*Alexandrium tamarense* *A. fundyense* *A. ostenfeldii*
Amnesic shellfish poisoning toxin (domoic acid)	*Pseudo-nitzschia multiseries* *P. pseudodelicatissima* *P. delicatissima* *P. seriata (?)*
Diarrhetic shellfish poisoning toxins (dinophysistoxin-1, okadaic acid)	*Prorocentrum lima*
None	*Chaetoceros convolutus* *C. concavicornis*
None	*Mesodinium rubrum*
Unknown	*Dictyocha speculum*
Unknown	*Chrysochromulina birgeri*
Unknown	*Mallomonas vanigera*
Unknown	*Leptocylindrus minimus*
"Ichthyotoxins"	*Gyrodinium aureolum*

long-term data bases such as this is expensive, but it enables researchers to discern trends and to eventually be able to discriminate between natural and possible human causes of HABs. The variable and complex dynamics of PSP toxicity in the Bay of Fundy would require an extensive and prohibitively expensive toxin monitoring program to cover the entire bay. Therefore, there is a year-round ban on the harvesting of blue mussels, as well as the permanent closure of several soft-shell clam harvesting sites. Finfish are sensitive to PSP toxins, as witnessed by historical mass kills of adult Atlantic herring[9] and by the mortality or impairment of larval and juvenile stages of fish.[10] The source of the PSP toxins in the Bay of Fundy is the dinoflagellate *Alexandrium fundyense* (Table 1), which originates offshore and is advected to inshore harvesting sites with a time lag of 2 to 3 weeks. Phytoplankton monitoring thus provides an advantage by indicating when to increase sampling of shellfish for PSP toxins, thereby ensuring that harvesting areas are promptly closed upon contamination and then re-opened after the danger has passed. Surveys of *A. fundyense* cysts in the sediments have shown that they are likely the primary source of the motile cells that initiate the annual summer blooms. A counterclockwise circulation pattern retains the cysts and vegetative cells within the Bay of Fundy.

The northern Gulf of St. Lawrence, particularly along the north and south shores of the lower estuary, the Gaspé peninsula and the Baie des Chaleurs (Fig. 1), has also historically encountered problems with PSP toxins in mussels and soft-shell clams.[11] The highest toxicity in molluscs is usually found along the north shore of the lower St. Lawrence estuary in August, when blooms of *Alexandrium tamarense* are promoted during periods of water column stability due to freshwater runoff.[12] A second PSP-toxin-producing species, *A. ostenfeldii*, has recently been found in these waters. The north shore is also the apparent reservoir for benthic cysts that initiate the *Alexandrium* blooms found to the immediate south.[13] After excystment, the motile dinoflagellate cells are transported across the estuary by a freshwater plume from the Manicouagan and Aux-Outardes rivers, to join the strong longshore Gaspé current that flows seaward. The resulting blooms can then contaminate molluscan shellfish along the south shore and around the Gaspé peninsula in late summer when the waters become stratified. This lengthy transport of cells and the complicated physical oceanography result in an erratic accumulation pattern of PSP toxins in molluscs along the south shore.[14] Compared to the Bay of Fundy, toxicity outbreaks in the Gulf of St. Lawrence are less regular and less predictable, making them even more difficult to monitor. Mussel growers can minimize chances of PSP contamination by harvesting in the fall or in the winter under ice cover, but they cannot avoid contamination simply by modifying the depth at which the mussels are maintained because toxic cells can be distributed throughout the water column.[11]

Until recently, the southern part of the Gulf of St. Lawrence was thought to be free from PSP toxins, despite its proximity to the Gaspé peninsula. However, an expanded monitoring program in 1988 found PSP toxins around the Gaspé peninsula, in the mouth of the Baie des Chaleurs, and also on the western and northern shores of Prince Edward Island (Fig. 1). In 1992, PSP toxins were found for the first time in east-central Nova Scotia,[3] where they continue to appear.

In Newfoundland, sporadic outbreaks of PSP toxicity, causing human illness, were reported for the first time in 1982, in Conception Bay (Fig. 1).[15] Since then, several harvesting sites have been temporarily closed, including Trinity Bay and Green Bay; at least four other areas remain permanently closed. Monitoring of shellfish tissue has increased along the northeast coast, where mussel and scallop culture industries have recently developed. Contrary to the lower latitudes, the incidence of PSP toxin is not confined to the summer-fall months, but is also reported throughout the winter at some sites. This makes it difficult to find windows of opportunity for harvesting. Newfoundland has no phytoplankton monitoring programs, but sampling has determined that resuspension of *A. fundyense* resting cysts from the sediments in the winter can lead to the occurrence of PSP toxins in mussels.[16] The importance of cysts, relative to vegetative *A. fundyense* cells, in contaminating the mussels is under examination.

Amnesic Shellfish Poisoning (ASP; domoic acid)

Until 1987, PSP was the major shellfish poisoning of concern in Canada. Then an outbreak of a new poisoning due to eating blue mussels from Cardigan Bay, eastern Prince Edward Island (Fig. 1), led to the discovery of amnesic shellfish poisoning.[17,18] The potent neuroexcitatory amino acid, domoic acid, was identified as the phycotoxin causing ASP. An expanded shellfish monitoring program, implementing a regulatory action limit of 20 μg domoic acid g^{-1} (= ppm) wet weight of shellfish tissue, has prevented any further cases of ASP in consumers.

The responsible organism in PEI is the pennate diatom *Pseudo-nitzschia multiseries* (previously called *Pseudonitzschia* [or *Nitzschia*] *pungens* forma *multiseries*), whose blooms have been restricted to the autumn. This is the first time that a diatom had been documented to produce a phycotoxin. The presence of a nontoxic species, *Pseudo-nitzschia pungens* (previously called *P. pungens* f. *pungens* and until recently considered a different form of the same species as *P. multiseries*), complicates programs that monitor for the presence of toxic phytoplankton. There are probable sources of domoic acid other than *P. multiseries* in the southeastern Gulf of St. Lawrence, including *P. delicatissima* and *P. seriata.*

The conditions that apparently contributed to the 1987 bloom were a prolonged dry period in summer followed by an unusually rainy autumn which may have provided nutrients via river runoff.[19] Fortunately, blooms of the toxic *P. multiseries* have dramatically declined in eastern PEI since the original 1987 Cardigan Bay episode, accounting for a parallel decrease in domoic acid levels in mussels since 1990. The last closures of shellfish harvesting were in northern PEI in October 1991 and 1994. The 1987 event resulted in an immediate cessation of mussel harvesting for several months (Fig. 2), causing a significant loss of revenue in PEI. However, consumer confidence quickly returned once the product was again declared safe and after the Department of Fisheries and Oceans (DFO) expanded its shellfish monitoring program; mussel production has continued to increase ever since (Fig. 2). At the same time, mussel growers have learned to cope with the presence of toxic *P. multiseries* by harvesting in adjacent but unaffected bays and by waiting for the mussels to naturally depurate the toxin.

The ensuing region-wide monitoring program resulted in the discovery of domoic acid in the southwest Bay of Fundy in blue mussels and soft-shell clams during August to October, 1988.[20] The predominant phytoplankter was *Pseudo-nitzschia pseudodelicatissima*, which was the source of the toxin.[21,22] Although this diatom is present annually, it is not always toxic and/or its concentration is not always high enough to contaminate shellfish; the last closure was in September 1995.

Since 1988, low levels of domoic acid have also been found in scallop digestive glands from Country Harbour and Whitehead (Fig. 1), on the southeast shore of Nova Scotia. Later, as part of a routine monitoring for phycotoxins in the roe-on scallop fishery, extremely high levels of domoic acid (up to 3,400 $\mu g\ g^{-1}$ of digestive gland) were found in sea scallops from Georges, German, and Browns Banks (Fig. 1) in May, 1995. No product reached the market, and all adductor muscles had domoic acid levels well below the safety guideline. However, this incident effectively stopped the Canadian scallop industry from further harvesting for the roe-on market in 1995. Immediately following this episode, increased monitoring revealed the presence of domoic acid near or exceeding the action level in various molluscan shellfish collected along the southwest coast of Nova Scotia, resulting in a temporary closure of that area. The great diversity in the types of organisms in which domoic acid was found would have been missed were it not for an unusually extended sampling effort. In July 1996, up to 99 µg domoic acid per gram of digestive gland were found for the first time in cultured sea scallops from the Annapolis Basin, Digby, Nova Scotia. The juvenile scallops have since depurated the toxin *in situ* and the whole animals have been marketed successfully. This episode has highlighted our need to better understand the kinetics of toxin uptake and depuration by different age groups of bivalve molluscs. The causative organism(s) in the above incidents has not been identified, although *P. seriata* was present during each of the events.

In 1994, low levels of domoic acid were found for the first time in cultured and wild mussels and in scallops in coastal Newfoundland (Fig. 1). No harvesting areas were closed because the levels remained low. Again, the source of the toxin is not known, although the potential domoic acid producers *P. seriata* and *P. delicatissima* are common components of the phytoplankton assemblage. It is essential that possible

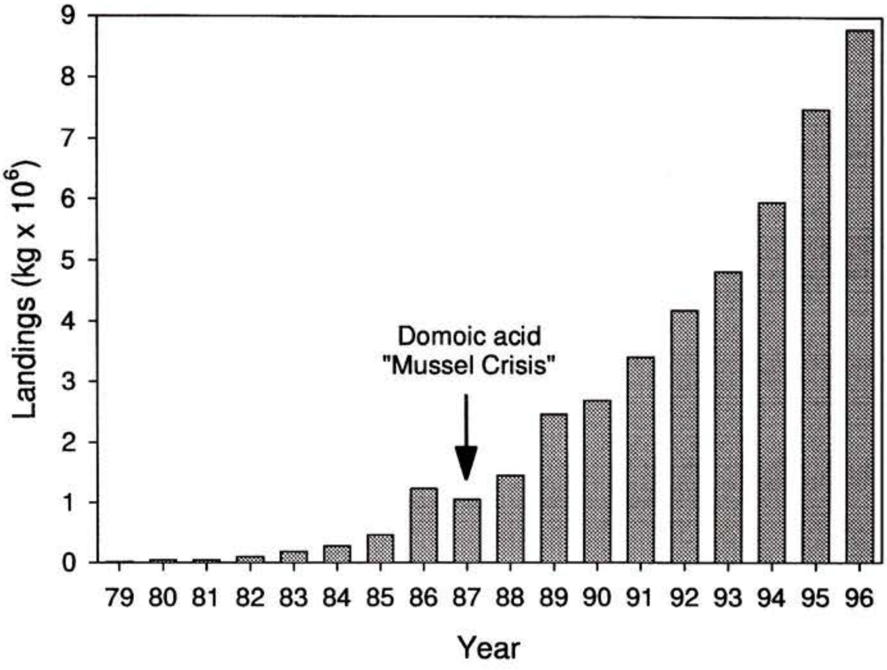


Fig. 2. Cultured mussel production in Prince Edward Island, 1979 to 1996 (Source: Fisheries and Oceans Canada and PEI Department of Fisheries and Environment).

toxigenic algal species be isolated into culture in order to confirm or rule out their ability to produce domoic acid. These episodes clearly indicate that domoic acid events continue to have important impacts on the molluscan shellfish industry.

Diarrhetic Shellfish Poisoning (DSP) Toxins

Diarrhetic shellfish poisoning is caused by one of the more-recently discovered phycotoxin groups, okadaic acid (OA) and its derivatives, such as dinophysistoxin-1 (DTX-1). Canada has established an interim regulatory action limit of 1 µg combined DTX-1 plus OA per gram of digestive gland, approximately equivalent to the Japanese limit. Because DSP toxins cause gastro-intestinal problems and OA is a tumour promoter, they are a concern to the aquaculture industry and to human health. The possible causative organisms, certain *Dinophysis* and *Prorocentrum* dinoflagellate species, have been noted in Canadian east coast waters since at least the early 1980s. However, there was no definitive proof of the existence of DSP toxins in Canada until July 1989. At that time, OA was identified for the first time in North America in natural phytoplankton assemblages from the lower St. Lawrence estuary and along the Gaspé coast.[23] The toxin was associated only with samples in which *Dinophysis norvegica* and *D. acuminata* were prominent.

Although DSP toxins had already been detected in Canadian waters, DSP was not officially acknowledged as a problem until August 1990. It was then that the first proven case of DSP in North America was confirmed when 13 people became ill after consuming cultured blue mussels from Mahone Bay, Nova Scotia[24] (Fig. 1). The toxin reported was DTX-1; no OA was found. Remnants of *D. norvegica* were found in the digestive glands of toxic mussels, but water samples were not available from this site at the time. A month later, a bloom of predominantly *D. norvegica* proved non-toxic. The following June, a minor *D. norvegica* bloom occurred in Mahone Bay, but OA and DTX-1 did not appear in the mussels until 3 to 4 weeks later, leading to doubt about the source of the toxicity.[25] Low levels of DTX-1 were again detected in mussels during both 1992 and 1993, as well as in 1994, in Ship Harbour, Nova Scotia. The source of the toxin could again not be determined.

One source of DSP toxins in eastern Canada is the dinoflagellate *Prorocentrum lima*. Evidence is accumulating that it may contaminate shellfish, as it grows epizootically on various substrates surrounding the mussels,[26] and strains of *P. lima* from the Mahone Bay site implicated in the DSP episode produced both OA and DTX-1 in unialgal culture.[26-28] This dinoflagellate has also been found in substantial numbers in the water column and attached to vegetation at aquaculture sites in the Miramichi estuary, New Brunswick (Fig. 1). Isolates from that site produced OA and DTX-1 in culture, indicating a potential threat to the recreational and commercial harvesting of molluscan shellfish. In the Bay of Fundy, trace levels of DTX-1 were found in mussels in September 1992. Unusually high numbers of *D. acuminata* were present at the time, but were not tested for toxins.

In 1993, high levels of DTX-1 (but no OA) were found for the first time in mussels from Bonavista Bay, Newfoundland[29] (Fig. 1). Many of the embayments in the vicinity were contaminated to variable amounts by the toxin. Several persons developed symptoms of what appeared to be DSP after consuming mussels from that area.[30] Harvesting was closed for the first time ever in Bonavista Bay due to DSP toxins, from October 1993 to August 1994. *Dinophysis norvegica* was the dominant species in the water column and was also present in the gut contents of the mussels during the Bonavista Bay incident, but *D. acuminata* and *P. lima* were also present. Low levels of DTX-1 have also since been found in bays of northern and southeast Newfoundland.

In each of the above examples it is impossible to unequivocally attribute the production of DSP toxins directly to a *Dinophysis* species as the evidence is only circumstantial. Another major paradox is that the appearance of several *Dinophysis* species, reputed to be toxic elsewhere in the world, is not always associated with the presence of DSP toxins in eastern Canada. Although more research is clearly required to resolve the question of *Dinophysis* toxicity, a major obstacle is that no one, anywhere in the world, has succeeded in culturing any *Dinophysis* species. Thus far, only *P. lima* has been conclusively shown to be a DSP toxin producer in Canada, and its link to DSP toxins in the field is still circumstantial.

Other Harmful and Toxic Algal Species

The harmful diatoms *Chaetoceros convolutus* and *C. concavicornis* cause serious economic losses of cultured salmonids in British Columbia. Finfish mortalities result from the physical disruption of gill function when the diatoms' barbed spines become lodged in the gills. On the Atlantic coast, these diatoms are regularly observed in the St. Lawrence estuary, Gulf of St. Lawrence, Baie des Chaleurs, and Newfoundland. *Chaetoceros convolutus* has also been found in the Bay of Fundy,[31] and *C. concavicornis* is present along the north shore of New Brunswick and in St. Margarets Bay, Nova Scotia. Thus far, cell numbers have been too low to observe any effect on fish. There is laboratory evidence, however, that the physiology of Atlantic salmon is impaired by short-term exposure to concentrations as low as 10 cells per mL. The presence of these *Chaetoceros* species is a potential impediment to developing (Newfoundland) and established (Bay of Fundy) salmon aquaculture industries.

Low numbers of the silicoflagellate *Dictyocha speculum* are commonly found in the lower St. Lawrence estuary, central and southeastern Gulf of St. Lawrence, and in Newfoundland. This organism has killed fish in Denmark and France, where the gills of affected farmed sea trout (*Oncorhynchus mykiss*) were clogged by mucus containing many *D. speculum* cells. It is not known if a toxin is produced.

In 1977, a dense bloom of the non-toxic, photosynthetic protozoan ciliate *Mesodinium rubrum* became trapped in a cove at Oven Head, in the Bay of Fundy, New Brunswick.[32] This caused oxygen depletion in the water where herring were being held captive in a weir, resulting in a major fish mortality. This organism was later implicated in an unusual event in Nova Scotia. In the spring of 1991, consumers of cultured mussels from Ship Harbour complained about a peppery taste, a sulfur-like smell, and a deep red-brown colour in the molluscs. Analyses for PSP, ASP, and DSP toxins proved negative. After "red" mussels reappeared in the spring of 1992, it was discovered that they had grazed on *M. rubrum* cells.[33] The red coloration originated from an obligate algal cryptomonad symbiont, which contains red phycoerythrin as an accessory photosynthetic pigment, living inside of the *M. rubrum* cells. Although the mussels were not toxic, their uncharacteristic colour and taste tend to decrease their appeal to consumers and are of continuing concern to the aquaculture industry.

The presence of other problematic algae in eastern Canada requires confirmation. For example, the prymnesiophycean flagellate *Chrysochromulina birgeri*, originally identified from Sweden, was associated with a massive kill of farmed Atlantic salmon under the ice in March 1996, in the brackish waters of the Bras d'Or Lakes, on Cape Breton Island, Nova Scotia[34] (Fig. 1). Fish kills near the same location in March 1994, may have been associated with a dinoflagellate tentatively identified as *Gymnodinium pascheri*, and a chrysophycean flagellate, *Mallomonas vanigera.*[34] The latter organism is characterized by long siliceous bristles which may have damaged the fish's gills in a manner analogous to *Chaetoceros convolutus* (see above). The presence of the dinoflagellate *Gyrodinium aureolum* within the Gaspé Current (Fig. 1) has been confirmed by immunological techniques.[35] This organism is known to have caused mass mortalities of finfish in northern Europe.

Finally, the chain-forming estuarine centric diatom *Leptocylindrus minimus* has been implicated in mortalities of cultured salmon and trout in southern Chile, but nowhere else in the world. The diatom is found in the Bay of Fundy[31] and Conception Bay, Newfoundland, although at concentrations considerably lower than that which caused the salmonid mortalities in Chile.

Phytoplankton Monitoring Programs

The examples of HABs described above have demonstrated the advantages of a phytoplankton monitoring program. These can be summarized as follows: 1) it provides scientific information about the initiation and decline of a HAB, given an adequate sampling frequency, such that potential causative factors may eventually be identified and predictive models developed; 2) it allows the correlation of the presence of known toxic or harmful algae with a measured phycotoxin or a finfish mortality; 3) it could provide an early warning of impending HABs, so that the sampling frequency for phycotoxins in molluscan shellfish can be increased as needed, and industry can make management decisions; 4) it identifies new toxic or harmful algal species; and 5) it builds a phytoplankton data base that can be used for scientific purposes and by the industry to establish sites for depuration plants or new harvesting leases.

There are nevertheless several potential disadvantages of phytoplankton monitoring programs: 1) the approach is ineffective if the HABs originate offshore and are rapidly advected toward inshore aquaculture sites where they promptly contaminate the animals before being advected back offshore, without being detected (such is the case for *Alexandrium tamarense* blooms in the southeast Gulf of St. Lawrence); 2) considerable training in taxonomy is required to correctly identify the phytoplankton species, especially those that are morphologically similar; 3) a rapid turnover time is required for the identification of HAB species if phytoplankton monitoring is to be successfully used as an early warning of impending toxic or harmful events; and 4) it is expensive to process samples (including the training of taxonomists, purchase of microscopes and technician time). Disadvantages 2 to 4 are slowly being overcome by the development of molecular probes that are specific to several of the major groups of toxic phytoplankton.(36) Several molecular probe techniques are being tested in various parts of the world prior to being marketed as "test kits"; others will become automated in the near future. It may therefore become cost-effective for the industry to carry out their own phytoplankton monitoring programs.

Unfortunately, the reality of recent cut-backs in funding by the federal government has resulted in the elimination of several phytoplankton monitoring programs.(37) For example, the program operated by the former DFO Inspection Branch at 32 sites in Prince Edward Island, New Brunswick, and Nova Scotia was canceled in April 1996, even though it was cost-effective during its initial years. The program was never recognized as being federally legislated and could not be relied upon to accurately predict the presence of toxins in the shellfish. Nevertheless, molluscan shellfish growers consider phytoplankton monitoring to be useful as an early warning and as a management tool, as it allows them to identify toxin-free periods for harvesting and marketing product.(37) In Nova Scotia, this gap has been filled by a limited phytoplankton monitoring program coordinated by the Aquaculture Association of Nova Scotia, in conjunction with the Nova Scotia Department of Fisheries and Aquaculture. Funding comes from the Canada – Nova Scotia Co-operative Agreement on Economic Diversification and from user fees. A DFO-operated phytoplankton monitoring program has operated since 1992 at Indian Point and Sambro, Nova Scotia. In the southwest Bay of Fundy, DFO monitors four sites for phytoplankton in support of the salmonid and shellfish aquaculture industries. A limited program is also being carried out by the Prince Edward Island Department of Fisheries and Environment, with assistance for sampling being provided by the Canadian Food Inspection Agency. In DFO's Laurentian Region, the Maurice Lamontagne Institute's Science Branch continues to monitor phytoplankton at 11 stations in the St. Lawrence estuary and gulf. One way to overcome the problem of limited fiscal resources is to establish more extensive partnering between scientists and the aquaculture industry, federal and provincial levels of government, universities, and provincial aquaculture associations.

Need for Concern?

Should the shellfish industry and aquaculturists still be concerned about HABs? Presently, the new Canadian Food Inspection Agency continues to monitor for the presence of phycotoxins in shellfish meat, thus insuring the safety of consumers and protecting the growers' interests. The incidences of some HABs (e.g., domoic-acid-producing *Pseudo-nitzschia* blooms) appear to be on the decline, leading one to believe that they are no longer of immediate concern. Mussel growers seem to be capable of coping with the presence of HABs, and consumer confidence in the safety of seafood seems to have returned.

In spite of the above, we must not become complacent. Aquaculturists must continue to be concerned about HABs and to support continued research. An apparent decrease in the frequency or intensity of local toxic events can lead to a false sense of security. Research in other parts of the world indicates that cycles of HABs are often unpredictable; even though a given area may show a decline or absence of HABs, it may again be seriously affected the following year. Experience has also shown that new toxic/harmful algal species or phycotoxins can appear at aquaculture sites, as witnessed by the 1987 "domoic acid crisis". A further example is the recent discovery, by the Institute for Marine Biosciences (NRC, Halifax, NS), of two new classes of lipid-soluble biotoxins in digestive glands of molluscan shellfish from selected areas of Nova Scotia.[38] Spirolides and prorocentrolide B are both "fast-acting" toxins which kill mice rapidly. The finding that spirolides occur seasonally (June and July) suggests a biological origin, while extracts from the dinoflagellate *Prorocentrum maculosum* display a similar toxicology to prorocentrolide B.[39]

The reality of federal government down-sizing, in both funding and staffing, has resulted in a substantial decrease in research and monitoring efforts on HABs. This contrasts with the situation in other countries, where governments (sometimes in partnerships with private industry) have increased their efforts to monitor and study HABs. For example, the United States has recently initiated a government sponsored inter-agency National Research Agenda on the Ecology and Oceanography of Harmful Algal Blooms (ECOHAB), which will provide about $3 million annually for HAB research over the next five years.[40]

Certainly, the east coast molluscan shellfish industry has expressed interest in research and monitoring programs.[37] For example, mussel growers in Nova Scotia ranked "phycotoxins" as a high biological concern for their industry.[41] At present there is little that aquaculturists can do to prevent the problem of phycotoxins and HABs. They can, however, protect their shellfish investment by letting contaminated animals depurate the phycotoxins naturally after the HAB ends or by harvesting in unaffected bays. In the longer run, information about causes of specific HABs may lead us to decrease coastal eutrophication, if that is shown to intensify HABs. Current research is also studying particular bacteria capable of degrading phycotoxins directly within certain shellfish.[42] Finally, because it is possible that molluscan shellfish may harbour toxic algal cells or cysts, knowledge about their presence will prevent their inadvertent spread to new areas (given proper ecological conditions) during transfer of shellfish from one bay to another.

There is no doubt that HABs will remain with us. Therefore, the best insurance is for growers to become educated about the problem of HABs and to develop partnerships with government and/or university scientists in order to further research and monitoring efforts. Industry could 1) provide sites for scientists to collect phytoplankton and monitor chemical and physical parameters of the water column; 2) collect samples which they could analyze or send to government or university laboratories; or 3) contribute funding, facilities, and/or equipment for joint venture operations. At a minimum, growers and scientists could meet to exchange information and share concerns. Governments will likely respond when aquaculture associations clearly voice their concerns about HABs. In this way, the Canadian aquaculture industry will be in a stronger position to contend with the next HAB episode.

References

1. Smayda TJ. 1990. In, *Toxic MarinePhytoplankton* (E Granéli, B Sundström, L Edler, DM Anderson, eds), p. 29-40. Elsevier Science Publishing Co., New York.
2. Hallegraeff GM. 1993. *Phycologia* 32:79-99.
3. Cembella AD, Todd E. 1993. In, *Algal Toxins in Seafood and Drinking Water* (IR Falconer, ed), p. 129-144. Academic Press, London.
4. Todd EDC. 1995. In, *Harmful Marine Algal Blooms* (P Lassus, G Arzul, E Erard, P Gentien, C Marcaillou, eds), p. 831-834. Lavoisier Science Publishers, Paris.
5. Shumway SE. 1990. *J. World Aquacult. Soc.* 21:65-104.
6. Wessells CR, Miller CJ, Brooks PM. 1995. *Mar. Resour. Econom.* 10:143-159.
7. Prakash A, Medcof JC, Tennant AD. 1971. *Bull. Fish. Res. Bd. Canada* 177: 87 p.
8. Martin JL, Richard D. 1996. In, *Harmful and Toxic Algal Blooms* (T Yasumoto, Y Oshima, Y Fukuyo, eds), p. 3-6. Intergov. Oceanogr. Comm., UNESCO, Paris.
9. White AW. 1984. In, *Seafood Toxins* (EP Ragelis, ed), p. 171-180. American Chemical Society, Washington.
10. White AW, Fukuhara O, Anraku M. 1989. In, *Red Tides: Biology, Environmental Science, and Toxicology* (T Okaichi, DM Anderson, T Nemoto, eds), p. 395-398. Elsevier Science Publishing Co., New York.
11. Desbiens M, Coulombe F, Gaudreault J, Cembella AD, Larocque R. 1990. In, *Toxic Marine Phytoplankton* (E Granéli, B Sundström, L Edler, DM Anderson, eds), p.459-462. Elsevier Science Publishing Co., New York.
12. Cembella AD, Therriault J-C. 1989. In, *Red Tides: Biology, Environmental Science, and Toxicology* (T Okaichi, DM Anderson, T Nemoto, eds), p. 81-84. Elsevier Science Publishing Co., New York.
13. Turgeon J, Cembella AD, Therriault, J-C, Béland P. 1990. In, *Toxic Marine Phytoplankton* (E Granéli, B Sundström, L Edler, DM Anderson, eds), p. 238-243. Elsevier Science Publishing Co., New York.
14. Larocque R, Cembella AD. 1990. In, *Toxic Marine Phytoplankton* (E Granéli, B Sundström, L Edler, DM Anderson, eds), p. 368-373. Elsevier Science Publishing Co., New York.
15. White RL, White AW. 1985. In, *Toxic Dinoflagellates* (DM Anderson, AW White, DG Baden, eds), p. 511-516. Elsevier, New York.

16. Schwinghamer P, Hawryluk M, Powell C, MacKenzie CH. 1994. *Aquaculture* 122:171-179.

17. Todd, ECD. 1993. *J. Food Protect.* 56:69-83.

18. Bates SS, Garrison DL, Horner RA. 1998. In, *Physiological Ecology of Harmful Algal Blooms* (DM Anderson, AD Cembella, GM Hallegraeff, eds), p. 267-292. Springer-Verlag, Heidelberg.

19. Smith JC, Cormier R, Worms J, Bird CJ, Quilliam MA, Pocklington R, Angus R, Hanic L. 1990. In, *Toxic Marine Phytoplankton* (E Granéli, B Sundström, L Edler, DM Anderson, eds), p.227-232. Elsevier Science Publishing Co., New York.

20. Haya K, Martin JL, Burridge LE, Waiwood BA, Wildish DJ. 1991. *J. Shellfish Res.* 10:113-118.

21. Martin JL, Haya K, Burridge LE, Wildish DJ. 1990. *Mar. Ecol. Prog. Ser.* 67:177-182.

22. Martin JL, Haya K, Wildish DJ. 1993. In, *Toxic Phytoplankton Blooms in the Sea* (TJ Smayda, Y Shimizu, eds), p. 613-618. Elsevier Science Publishers, Amsterdam.

23. Cembella AD. 1989. *J. Appl. Phycol.* 1:307-310.

24. Quilliam MA, Gilgan MW, Pleasance S, De Freitas ASW, Douglas D, Fritz L, Marr JC, Smyth C, Wright JLC. 1993. In, *Toxic Phytoplankton Blooms in the Sea* (TJ Smayda, Y Shimizu, eds), p. 547-552. Elsevier Science Publishers, Amsterdam.

25. Watson-Wright W, Smyth C, Sims G, Marr J, Lawrence J, Sinclair D, Gilgan M. 1992. In, *Emerging Food Safety Problems Resulting from Microbial Contamination* (K Mise, JL Richard, eds), p. 69-79. Kouken Shupan, Inc., Tokyo.

26. Lawrence J, Bauder A. Institute for Marine Biosciences, National Research Council, Halifax, NS, pers. commun.

27. Marr JC, Jackson AE, McLachlan JL. 1992. *J. Appl. Phycol.* 4:17-24.

28. Jackson AE, Marr JC, McLachlan JL. 1993. In, *Toxic Phytoplankton Blooms in the Sea* (TJ Smayda, Y Shimizu, eds), p. 513-518. Elsevier Science Publishers, Amsterdam.

29. Gilgan MW, van de Riet J, Dorey M, Burns BG. 1995. In, *Harmful Marine Algal Blooms* (P Lassus, G Arzul, E Erard, P Gentien, C Marcaillou, eds), p. 291-296. Lavoisier Science Publishers, Paris.

30. McKenzie CH, Paranjape M, Powell C, Gilgan MW, Quilliam MA. 1994. In, *Proceedings of the Fourth Canadian Workshop on Harmful Marine Algae* (JR Forbes, ed), p. 26 (abstract). *Can. Tech. Rep. Fish. Aquat. Sci.* 2016.

31. Martin JL, Wildish DJ, LeGresley MM, Ringuette MM. 1995. *Can. Manuscr. Rep. Fish Aquat. Sci.* 2277: 154 p.

32. Martin JL, Wildish DJ. 1990. *Bull. Aquacult. Assoc. Can.* 90-4: 19-21.

33. Carver CE, Mallet AL, Warnock R, Douglas D. 1996. *J. Shellfish Res.* 15:191-201.

34. Caraver CE. Mallet Research Services Ltd., Dartmouth, NS, pers. commun.

35. Blasco D, Bérnard-Therriault L, Levasseur M, Vrieling EG. 1996. *J. Plank. Res.* 18:1917-1930.

36. Scholin CA. 1998. In, *Physiological Ecology of Harmful Algal Blooms* (DM Anderson, AD Cembella, GM Hallegraeff, eds), p. 337-349. Springer-Verlag, Heidelberg.

37. Bates SS, Keizer PD (eds). 1996. *Proceedings of the Workshop on Harmful Algae Research in the DFO Maritimes Region. Can. Tech. Rep. Fish. Aquat. Sci.* 2128: 44 p.

38. Hu T, Oshima Y, Quilliam MA, Watson-Wright WM, Wright JLC. 1995. *J. Chem Soc. Chem. Commun.* 1995:2159-2161.

39. Wright JLC, Cembella AD. Institute for Marine Biosciences, National Research Council, Halifax, NS, pers. commun.

40. http://www.geo.nsf.gov/oce/docs/ao-hab.htm; http://www.redtide.whoi.edu/hab/nationplan/nationplan.html.

41. Freeman KR. 1996. *Can. Tech. Rep. Fish. Aquat. Sci.* 2125: 32 p.

42. Osada M, Stewart JS. 1997. *Aquat. Microbial. Ecol.* 12:203-209.

Stephen Bates is a Research Scientist at Fisheries and Oceans Canada, Gulf Fisheries Centre, P.O. Box 5030, Moncton, NB Canada E1C 9B6; e-mail: BatesS@mar.dfo-mpo.gc.ca.

Impacts of harmful algae on the west-coast aquaculture industry and a National Research Plan by the Phycotoxins Working Group of Fisheries and Oceans Canada to address such issues

J.N.C. (Ian) Whyte

Paralytic shellfish poisoning (PSP) and amnesic shellfish poisoning (ASP) are the main human health issues related to toxic algae on the west coast of Canada. Records of bivalve toxicity, resulting in closures of shellfish harvesting areas and adversely impacting the industry, show spatial, seasonal and yearly variance in toxic bloom events. Dense blooms of non-toxic algae such as *Gonyaulax spinifera* have caused death of bivalve molluscs from smothering and anoxia. Species of *Dinophysis* and *Prorocentrum* associated with diarrhetic shellfish poisoning (DSP) have not caused human illnesses on the Pacific coast. The economic impacts on the shellfish industry from harmful algae are related to costs associated with monitoring to protect public health, harvest closures when toxin levels exceed allowable levels, resultant shellfish mortalities, and reduced sales because of loss in consumer confidence. Toxic *Heterosigma carterae* is the major killer of farmed salmon, with cumulative losses in excess of $15 million. Physical obstruction of the gills of salmon from the non-toxic diatoms *Chaetoceros convolutus*, *C. concavicornis*, *Dictyocha speculum* and *Skeletonema costatum* have caused death of fish from excess mucus formation and anoxia. Culture technologies are being developed that isolate fish from the effects of harmful algae; however, such technologies are less practical with shellfish species. The Department of Fisheries and Oceans Phycotoxins Working Group recently developed a National Research Plan that identified the priority areas of research as: phytoplankton monitoring with respect to harmful algal blooms, uptake and depuration of biotoxins, harmful algal bloom dynamics, impacts and management approaches, and improved analytical methodology. Research addressed under these categories will provide the scientific knowledge that affords early warning of harmful bloom events and the protocols necessary to mitigate the adverse impacts harmful algae elicit on cultured fish and shellfish.

Introduction

Harmful algal blooms are natural phenomena that appear to be increasing in frequency throughout the world.[10,19] Marine ecosystem stress, caused by a number of factors, may play a role in the apparent increased frequency and persistence of blooms, which can be spatially extensive or patchy and episodic. Stress factors include coastal development, dumping of wastes, habitat degradation, river basin runoff, excessive nutrient loading, toxic effluents, over-exploitation of resources, fallout of aerosol contaminants, and possibly global climate change. On the west coast of Canada there is no conclusive evidence of human-mediated factors playing a role in bloom events. Over the past 20 years, shellfish and finfish aquaculture have expanded significantly on this coast. However, general failure to acknowledge the yearly occurrence of harmful algae blooms at specific sites has resulted in severe economic hardship to aquaculturists.[25]

Impacts on Shellfish

Algal species

Filter-feeding molluscan bivalves concentrate toxins from microalgae that when ingested by humans can cause illness and death. On the Pacific coast, bivalve contamination is mainly from paralytic shellfish poisoning (PSP) or amnesic shellfish poisoning (ASP) toxins.[15,28] Illnesses from diarrhetic shellfish poisoning (DSP) have not been reported on this coast, even though algae are present that are known to produce DSP elsewhere in the world.[26]

The causative agents of PSP, saxitoxin and derivatives, are produced principally by the dinoflagellate *Alexandrium* (formerly *Protogonyaulax* and *Gonyaulax*). Species identified on the west coast are *A. catenella*, *A. acatanella*, *A. tamarense A. ostenfeldii* and *A. hiranoi.*[15,24-26] Despite detailed toxicity monitoring at some 90 sites along the coast of British Columbia, some 70 % of the coastline remains permanently closed to bivalve harvesting because of lack of monitoring. In general, the toxicity in shellfish is highest in late autumn and early winter.[3,4] However, seasonal and yearly variation in toxicity in the sentinel mussel, *Mytilus californianus*, can be quite site-specific. Monitoring of toxins by the Inspection Branch of the Department of Fisheries and Oceans (now the Canadian Food Inspection Agency) has indicated the periods of toxicity in certain areas are consistent from year to year (Fig. 1). Peak levels of PSP toxicity occur in the fall at Grappler Inlet in Barkley Sound, on the southwest coast of Vancouver Island (Fig. 1a). Opposite the northeast corner of Vancouver Island at Echo Bay maximum levels of toxicity occur in the spring (Fig. 1b). Farther south in the Strait of Georgia at Sechelt Inlet, opposite east central Vancouver Island, the incidence of toxicity occurs in the fall (Fig. 1c). Farther south in the Strait of Georgia at Vesuvius Bay on Saltspring Island off the southeast corner of Vancouver Island toxin concentrations peak in the summer (Fig. 1d). Figure 1 illustrates that the selection of sites for bivalve cultivation based on historic toxicity records or by current monitoring data has considerable merit.

Amnesic shellfish poisoning (ASP) is caused by the neurotoxin domoic acid. This toxin is produced by *Pseudo-nitzschia* spp.[30] and was first discovered in mussels from Prince Edward Island in 1987 where it caused the death of three elderly people and 107 illnesses. It also severely impacted the economy of the Atlantic molluscan aquaculture industry.[29] On the British Columbia coast, domoic acid was first identified in 1992 in the crab, *Cancer magister*, from Holberg Inlet on Vancouver Island. Since then annual closures to crab harvesting have resulted from levels exceeding the allowable 20 μg/g in the viscera. It is thought that some species, such as the scallop *Chlamys hastata*, may be the vector for the crab toxicity. Free-swimming *Chlamys* scallops, when exposed to domoic acid by feeding on *Pseudo-nitzschia multiseries*, lose motor or escape responses and would easily fall prey to bottom dwelling scavengers such as crabs.[35] ASP has been found in most areas of the British Columbia coast and evidence suggests that coastal contamination may be associated with advection of offshore blooms of *Pseudo-nitzschia* spp.[7] Corroboration of this is suggested by the increased toxin level in the razor clam, *Siliqua patula*, collected from the west coast of Vancouver Island after severe storms.[33] Closure of the razor clam and crab fisheries because of unacceptably high levels of domoic acid have severely impacted the economies of small fishing communities in the Queen Charlotte Islands. Other molluscan species, including oysters, mussels and littleneck clams, do not demonstrate shell gaping from loss in motor response when intoxicated with domoic acid and are therefore unlikely vectors for the toxin in the crab.[34-36] Domoic acid in *Pseudo-nitzschia multiseries* also causes feeding inhibition in the rotifer, *Brachionus plicatilis*, with a subsequent reduction in nutritional condition and fecundity.[37] Similar effects on other secondary producers in the marine foodweb would have significant adverse effects on recruitment of finfish species.

Dinoflagellates of the *Dinophysis* and *Prorocentrum* genera are the principal sources of the toxin causing diarrhetic shellfish poisoning (DSP). The toxin okadaic acid and its derivatives DTX 1-3 have caused illness in humans in Atlantic Canada.[8] However, the presence of *Dinophysis norvegicus*, *D. acuminata*, *D. fortii* and *D. ovum* on the west coast have caused no illnesses.[11]

Dense blooms of other non-toxic algae can cause death of bivalves from smothering and anoxia. *Gymnodinium sanguineum* blooms are an annual occurrence in British Columbia.[31] A bloom of *Gonyaulax spinifera* off the coast of Vancouver Island in 1990 was the largest ever recorded in British Columbia, extending about 400 km alongshore and as far as 100 km offshore.[6,9] Advection of the bloom on-shore caused losses of over $200,000 to the shellfish aquaculture industry in Barkley Sound from mortalities to juvenile clams caused by oxygen depletion on senescence. *Ceratium fusus* has been implicated in the death of prawns but the causative agent is unknown.[17] Non-toxic marine organisms producing distinctive "red" tides are the predatory dinoflagellate *Noctiluca scintillans* and the ciliated protozoan *Mesodinium rubrum*. The former may be detrimental in high concentrations to fish through ammonia production,[14] and the latter can impart an unacceptable taste and red pigmentation to shellfish flesh.[5]

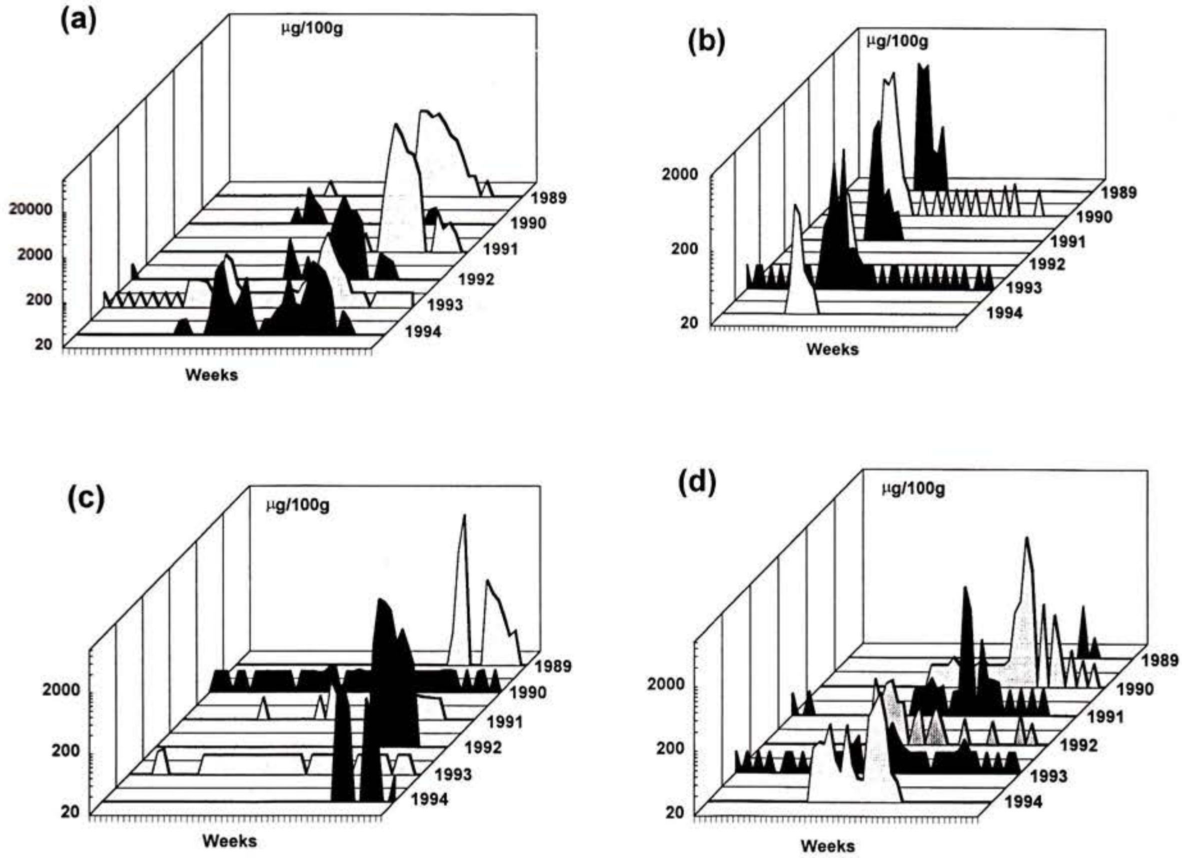


Figure 1. Seasonal and yearly variations in the concentration of PSP in the mussel, *Mytilus californianus*, collected from (a) Grappler Inlet in Barkley Sound, (b) Echo Bay on Gilford Island, (c) Egmont/Secret Bay, in the Sechelt Inlet, and (d) Vesuvius Bay on Saltspring Island. Base levels in the figures indicate samples were not collected, the "plateau" levels at 40 µg/100 g indicate no detectable PSP in the samples; note that the y axis is logarithmic. Values were abstracted from published DFO Inspection Branch Summaries of Marine Toxin Records in the Pacific Region from 1989 to 1994.

Monitoring

Closure of shellfish areas to harvesting is based on the monitoring of phycotoxin levels in shellfish rather than on the number of causative phytoplankton in the water, as in many European countries. Monitoring for PSP toxins is carried out by the Canadian Food Inspection Agency at regularly sampled sites on the coast. Samples are taken weekly in the spring, summer and early autumn, and less often in the winter months. Testing is by mouse bioassay and harvesting closures are initiated when PSP toxins in excess of 80 μg STXeq/100 g of shellfish tissue are detected. Domoic acid is analysed in shellfish tissue using methanol extraction and analyte quantification by HPLC. Harvesting closures are imposed when domoic acid levels in the flesh exceeds 20 μg/g. In addition to the HPLC analyses, the mice involved in the PSP bioassay are observed for characteristic responses to domoic acid toxicity. Studies of the uptake and depuration of domoic acid by the mussel *Mytilus californianus* demonstrated that it was adequate as a sentinel organism for weekly monitoring of this water-soluble toxin.[34] In 1996, over 3,500 shellfish samples were analysed for biotoxins in the Inspection Branch laboratory on the west coast of Canada.[18] No routine monitoring for DSP is conducted on the west coast.

Economic impact

Estimates of economic losses to the shellfish industry caused by harmful algae are difficult to obtain. Economic considerations include costs associated with monitoring to protect public health, closures of aquaculture or harvest sites, delays in harvesting shellfish, loss on disposal when harvested shellfish have toxin levels exceeding allowable levels, relaying or commercial depuration of toxic stocks, resultant shellfish mortalities, loss in consumer confidence with reduced sales at market, and medical treatment required by affected victims.

Impacts on finfish

Algal species

The raphidophyte *Heterosigma carterae* [1] and the diatoms *Chaetoceros concavicornis*, *C. convolutus*,[16,38,39] *Corethron criophilum*,[20] *Skeletonema costatum* and *Thalassiosira* spp.[13] have killed cultured salmonids in British Columbia, with economic losses in excess of $15 million.[24] Raphidophytes kill the fish by producing ichthyotoxins or superoxide radicals, and hydrogen peroxide, which can strip the mucus from fish gills leading to osmoregulatory failure and death.[22,23,32,39] Diatoms initially cause a massive increase in production of gill mucus, despite no sign of penetration by the spines of the diatoms, followed by degenerative changes of the gill epithelium. Hypoxia due to respiratory dysfunction is the ultimate cause of death.[16,38,39] Other harmful species found in low numbers in west coast waters and causing no recorded adverse effects on cultured finfish, are *Chrysochromulina polylepis*, *Gyrodinium aureolum*, *Phaeocystis pouchetii*, *Leptocylindrus minimus*, and *Dictyocha speculum* (formerly *Distephanus speculum*). These species have caused considerable economic loss to cultured fish elsewhere in the world.[2]

Monitoring

No comprehensive monitoring of phytoplankton is currently conducted on the west coast. In previous years a phytoplankton watch program was conducted that provided farm data reports on harmful species in the area. A telephone message system listing all problem areas was available to callers. The coordinator of this program also trained personnel and checked sampling procedures to improve the quality of the data.[21] Most salmon farms now have monitoring regimes for detection of harmful algae at their individual sites.

Economic impact

Harmful algae cause estimated annual losses of about $1 million to cultured salmon stocks and another $4 million in indirect losses to the economy. Costs associated with the development of new technologies to mitigate the effects of harmful algae, such as enclosed bag cultivation, adds significantly to the overall cost of alleviating the problems.

Potential for alleviating impacts

The development of rapid field tests for application at aquaculture and harvesting sites would provide early detection of toxicity and allow harvest management. Although test kits have been developed, none are yet approved for public health inspection programs.[12] British Columbia currently has five registered depuration plants for shellfish fecal coliform decontamination. Development of protocols for depuration of phycotoxins in commercial plants is needed. Domoic acid clearance is feasible in many commercial species.[34,35] Selection of shellfish growing sites relatively free from annual blooms of toxic algae would seem critical for aquaculture to be viable. The development and application of new technologies such as satellite imagery, airborne sensors, *in situ* moored bio-optical sensors and other physical sensing techniques are essential for continuous monitoring and forecasting of bloom events. Training of on-site farm personnel in sampling and identification of harmful algae would assist in early bloom predictions. Controlling or eliminating algal blooms by applying chemicals, flocculants, viruses, bacteria and parasites may be feasible, but the ecological consequences of chemical and biological control have yet to be evaluated.

Mitigating the adverse effects on farmed fish must ultimately rely on improved husbandry, technologies, and procedures that include monitoring of algae in the water column at the farm sites. Site selection for fish farms is fundamentally important because bloom events are annual occurrences in certain coastal areas. Bloom avoidance can be managed by moving pens away from an encroaching bloom; however this can be equally stressful and lethal to caged fish. Stationary pens can be made deeper to allow the fish to swim below the surface bloom, or can be constructed in a manner that allows for lowering of the pens during a surface bloom. Perimeter skirting of pens with polyester aprons allows for upwelling of deeper colder water, either by aeration or using air-lift or hydraulic pumps. Application of these techniques prevents advection of surface blooming algae into the pens, reduces any anoxic conditions caused by the algae, and inhibits growth of many algae by lowering water temperatures. De-stratification of the water column by vertical convection also inhibits growth of flagellates, such as *H. carterae,* that require calm stratified water for growth. Care should be exercised in using these techniques with blooms of harmful diatoms because maximum cell densities of these species can be at depths of 20 m; hence the need for accurate monitoring of the water column. Newly developed self-contained bag-culture systems for fish using PVC-coated woven polyester bags promises to negate many of the problems associated with harmful algae. The level of the water intake can be controlled to avoid blooms adjacent to the pens. If contact with the bloom cannot be avoided, then losses can be reduced by lowering the oxygen demand and general stress on the fish. This can be achieved with strategies that discourage the fish from moving into a surface bloom, such as cessation of feeding just prior to and during the bloom, and minimizing personnel traffic on the walkways. It is particularly important to lower oxygen demands on exposed fish because most harmful algae damage the gills. Therapeutic use of the mucolytic agent, L-cysteine ethyl ester, in the feed of salmonids to inhibit production of gill mucus during exposure to natural blooms of *Chaetoceros concavicornis*, has yet to be fully evaluated.

Phycotoxins Working Group of the Department of Fisheries and Oceans

The Phycotoxins Working Group (PWG) was established in 1988 to apprise senior management within DFO on harmful algae including planning, co-ordinating and prioritising research activities. Membership of this national advisory group consists of project leaders from the five DFO regions across Canada, a national shellfish co-ordinator from the Canadian Food Inspection Agency, and an executive secretary from senior management. Included in the mandate for the PWG is the organisation of the biannual Canadian Workshop on Harmful Marine Algae. Some of the problems stemming from blooms of harmful algae alluded to previously were developed into research priorities and formed the basis of a *DFO National Research Plan* relating to harmful algae. Priority research topics deemed of national importance were:

- phytoplankton monitoring with respect to harmful algal blooms;
- uptake and depuration of biotoxins;
- harmful algal bloom dynamics, impacts and management approaches; and
- improved analytical methodology.

Short and long term research activities conducted within the framework of the plan would provide knowledge of the biological and oceanographic conditions controlling population dynamics of harmful algae, the impacts of harmful algae on foodweb organisms and commercial species, the mechanisms triggering the production of biotoxins, the kinetics of uptake and depuration of biotoxins in commercial species and other marine foodweb organisms, and the protocols needed for improved identification and quantification of biotoxins. The knowledge gained would:

- minimise economic losses to traditional and aquacultured fisheries;
- minimise health hazards that impact negatively on the economy and on public health;
- provide predictive solutions for management of fisheries resources affected by harmful algae;
- preserve biotoxin-free areas;
- select sites suitable for aquaculture; and
- minimise impacts on the aquatic ecosystem.

Proposed research topics on uptake and depuration of biotoxins were further developed as a theme, providing more immediate resolution to problems associated with traditional and aquacultured fisheries. Achievement of goals was based on the following study objectives:

- kinetics of uptake, distribution, biotransformation, and clearance of biotoxins in commercial species of shellfish and finfish;
- physiological effects of accumulated phycotoxins on commercial species;
- uptake, depuration, fate and toxicological effects of biotoxins on aquatic foodweb organisms;
- development of technologies and protocols for clearance of biotoxins from contaminated shellfish and finfish.

Attainment of these objectives would provide:

- species-specific rates for biotoxin assimilation and depuration;
- the kinetics of accumulation and distribution in body parts of shellfish and finfish;
- an understanding of biotoxins transfer through aquatic foodwebs and the physiological and toxicological effects on food chain organisms;
- an assessment of recruitment damage;
- the ability to forecast and manage resources, with risk assessment of cultured species affected by biotoxins contamination;
- the development of procedures to decrease uptake rates or enhance depuration rates of biotoxins;
- the development of affordable methodologies for efficient depuration of biotoxins in commercial depuration plants;
- the identification of viable culture sites and species of shellfish suitable for these sites;
- strategies for minimising the effects of harmful algal blooms; and
- the identification of shellfish species suitable as sentinel species for monitoring biotoxins.

It is the hope of the PWG that many of these research topics can be conducted in partnership with personnel in the shellfish and finfish industries, universities and other national or international research institutes. A multidisciplinary, scientific and pragmatic approach to understanding harmful algal blooms and phycotoxins will reduce the risk to public health and the economic hardships caused by these natural phenomena.

References

1. Black EA, Whyte JNC, Bagshaw JW, Ginther NG. 1991. *J. Appl. Ichthyol.* 7:168-175.
2. Bruslé JJ. 1995. *IFREMER Rep Pres Oc Jan* No. 10, 75 p.
3. Chiang RMT. 1985. In, *Toxic Dinoflagellates* (DM Anderson, AW White, DG Baden, eds), p. 451-456. Elsevier, New York.
4. Chiang RMT. 1988. *J. Shellfish Res.* 7: 637-642.
5. Douglas DJ, Carver CE, Warnock RE. 1992. In, *Proceedings of the Third Canadian workshop on Harmful Marine Algae* (JC Therriault, M Levasseur, eds), p. 33-34. *Can. Tech. Rep. Fish. Aquat. Sci.* 1893.
6. Forbes JR, Borstad GA, Waters R. 1990. *Red Tide Newsletter* 3:2-3.
7. Forbes JR, Denman KL. 1991. *Can. J. Fish. Aquat. Sci.* 48:960-967.
8. Gilgan MW, Powell C, van de Riet J, Burns BG, Quilliam MA, Kennedy K, McKenzie CH. 1994. In, *Proceedings of the Fourth Canadian Workshop on Harmful Marine Algae* (JR Forbes, ed.), p. 13-14. *Can. Tech. Rep. Fish. Aquat. Sci.* 2016.
9. Gower JFR. 1991. In, *Pacific Coast Research on Toxic Marine Algae* (JR Forbes, ed), p. 11-21. *Can. Tech. Rep. Hydrogr. Ocean Sci.* 135.
10. Hallegraeff GM. 1993. *Phycol.*, 32:79-99.
11. Haigh R, Taylor FJR. 1990. *Can. J. Fish. Aquat. Sci.* 47:2339-2350.
12. Jellet JF, Wood CR, Belland ER, Doucette LI. 1996. In: *Proceedings of the fifth Canadian workshop on harmful marine algae* (RE Penney, ed.), p. 7-12. *Can. Tech. Rep. Fish. Aqua. Sci.*, 2138.
13. Kent ML, Whyte JNC, LaTrace C. 1995. *Dis. Aquat. Org.* 22:77-81.
14. Okaichi T, Nishio S. 1976. *Bull. Plankton Soc. Japan* 23:25-30.
15. Quayle DB. 1969. *Bull. Fish. Res. Bd. Can.* 168:68 p.
16. Rensel JE. 1993. In, *Toxic Phytoplankton Blooms in*

the Sea (TJ Smayda, Y Shimizu, eds), p. 625-630. Elsevier Science Publishers, New York.

17. Rensel JE, Prentice EF. 1980. *U.S. Dept. Commerce, Fish. Bull.* 78:781-788.
18. Schallié, K. Personal communication.
19. Smayda TJ. 1990. In, *Toxic Marine Phytoplankton* (E Granéli, B Sundstroem, L Edler, DM Anderson eds), p. 29-40. Elsevier Science Publishers, New York.
20. Speare DJ, Brackett J, Ferguson HW. 1989. *Can. Vet. J.* 30:571-575.
21. Stockner E. 1991. In, *Pacific Coast Research on Toxic Algae* (JR Forbes, ed), p. 63-64. *Can. Tech. Rep. Hydrogr. Ocean Sci.* 135.
22. Tanaka K, MutoY, Shimada M. 1994. *J. Plankton Res.* 16:161-169.
23. Tanaka K, Yoshimatsu S, Shimada M. 1992. *Experientia* 48:888-890.
24. Taylor FJR. 1985. In, *Toxic dinoflagellates* (DM Anderson, AW White, DG Baden, eds), p. 11-26. Elsevier, New York.
25. Taylor FJR. 1993. In, *Toxic Phytoplankton Blooms in the Sea* (TJ Smayda, Y Shimizu, eds), p. 699-703. Elsevier Science Publishers B.V., Amsterdam.
26. Taylor FJR, Haigh R. 1996. *Can. J. Fish. Aquat. Sci.* 53:2310-2322.
27. Taylor FJR, Haigh R, Sutherland TF. 1994. *Mar. Ecol. Prog. Ser.* 103:151-164.
28. Taylor FJR, Horner RA. 1994. In, *Review of the Marine Environment and Biota of Strait of Georgia, Puget Sound and Juan de Fuca Strait: Proceedings of the B.C. Washington Symposium of the Marine Environment* (RCH Wilson, RJ Beamish, F Aitkens, J Bell, eds), p.175-186. *Can. Tech. Rep. Fish. Aquat. Sci.* 1948.
29. Todd ECD. 1993. *J. Food Protection* 56: 69-83.
30. Villac MC, Roelke DL, Chavez FP, Cifuentes LA, Fryxell GA. 1993. *J. Shellfish Res.* 12:457-465.
31. Watanabe LN, Robinson MG. 1979. *Royal Roads Military College, Coastal Mar. Sci. Lab. Man. Rep.* 79 (9), 60 p.
32. Whyte JNC. 1991. In, *Pacific Coast Research on Toxic Marine Algae* (JR Forbes, ed), p. 3-8. *Can. Tech. Rep. Hydrogr. Ocean Sci.* 135.
33. Whyte, JNC. Unpublished data.
34. Whyte JNC, Ginther NG, Townsend LJ. 1993. In, *Harmful Algal Blooms* (P Lassus, G Arzul, E Erard-Le Denn, P Gentien, C Marcaillou, eds), p. 531-537. Lavoisier Science Publishers, Paris.
35. Whyte JNC, Ginther NG, Astrope LJ. 1996. In, *Proceedings of the Fifth Canadian Workshop on Harmful Marine Algae* (RE Penney, ed), p. 103. *Can. Tech. Rep. Fish. Aqua. Sci.* 2138.
36. Whyte JNC, Jones TO, Ginther NG, Townsend LD. 1996. *Bull. Aqua. Assoc. Can.*, 96:73-75.
37. Whyte JNC, Townsend LD, Ginther NG. 1996. In, *Harmful and Toxic Algal Blooms* (T Yasumoto, Y Oshima, Y Fukuyo, eds), p 401-404. International Oceanographic Commission of UNESCO.
38. Yang CZ, Albright LJ. 1992. *Dis. Aquat. Org.* 14:105-114
39. Yang CZ, Albright LJ. 1994. *Can. J. Fish. Aquat. Sci.* 51: 2493-2500.
40. Yang CZ, Albright LJ, Yousif AN. 1995. *Dis. Aquat. Org.* 23: 101-108.

J.N.C. (Ian) Whyte is a Research Scientist with Fisheries and Oceans Canada, Pacific Biological Station, 3190 Hammond Bay Road, Nanaimo, B.C., V9R 5K6

AAC Special Publication No. 3

Aquaculture Career and Training Directory

A joint publication of the Canadian Aquaculture Industry Alliance and the Aquaculture Association of Canada produced with the support of Human Resources Canada

- *Institutions:* list of 47 universities, colleges, and other institutions offering training and education programs;
- *Programs:* 74 degree, diploma, certificate and other training opportunities for study and upgrading;
- *Industry Organizations:* national and regional organizations in the industry;
- *Getting to Know the Industry:* answers to questions such as "Why choose a career in aquaculture?" and "Is aquaculture the right career for me?"

Available for $9.95 (includes postage; Visa and Mastercard accepted) from:

Aquaculture Assocation of Canada
P.O. Box 1987, St. Andrews, N.B., Canada EOG 2XO
fax 506 529-4609, e-mail aac@wolves.sta.dfo.ca

Managing shellfish aquaculture sites in the presence of harmful algae

John W. Hurst Jr.

Monitoring for paralytic shellfish poisoning (PSP) toxin began in Maine in 1958 and the state currently has a coast-wide monitoring program. An extensive database of 80,000 samples has accummulated over the past 20 years, allowing the management of shellfish harvest areas by species. There has been some success in predicting when and where PSP toxin will occur each year. Sampling results have indicated there are areas on the Maine coast that are expected to be toxin-free and some of these locations are being used by aquaculturists. Seven species of shellfish have been approved for aquaculture in Maine and we have some knowledge of how readily the various species become toxic and the rate at which they depurate. Aquaculturists can use this information in managing their leases and selecting the appropriate species to raise. Two other toxins, amnesic shellfish poisoning (ASP) and diarrhetic shellfish poisoning (DSP), are also of concern. Domoic acid is present at low levels and is a potential problem. ASP has never been reported in Maine, but should be considered as "a toxin waiting to occur" as the algae that produce the toxin are present in Maine waters.

I am convinced that data derived from Maine's monitoring program for paralytic shellfish poisoning can aid aquaculturists in the safe management of their leases. The Marine Shellfish Toxins Monitoring Program, as established by the Maine Legislature, states its purpose as follows:

> "A comprehensive Marine Shellfish Toxins Monitoring Program is established to protect the public health while providing for the harvest of susceptible species of marine mollusks in areas not shown to be affected by contamination."

This statement made it public policy for the Maine Department of Marine Resources to develop the present PSP toxin monitoring program.

Monitoring for paralytic shellfish poisoning began in Maine in 1958. Following a serious outbreak of PSP in nearby Canadian waters in 1957, five monitoring sites were established in eastern Maine. Closures were made in portions of the monitored areas in 1958, 1959, 1961, 1964, 1969 and 1972. This limited monitoring program, coupled with results from Canada, provided adequate protection of public health in eastern Maine. Prior to 1972, tests were only occasionally conducted on the rest of the coast. Expanded sampling in 1961 resulted in the permanent closure of two areas around Matinicus and Monhegan Islands, as these areas were not being regularly sampled. Until 1972, no other areas were closed to shellfish harvesting, although occasional low toxin scores were recorded.

In 1972, an area in eastern Maine was closed to shellfish harvesting in early August and by mid-September it was evident that shellfish were extremely toxic in the area extending from Cape Ann, Massachusetts, into western Maine. Shellfish beds from Cape Elizabeth to New Hampshire were closed to harvesting on September 15th and the entire Maine coast was closed on September 17th.

There were no closures in 1973, other than in the historical area in eastern Maine. The following year was one of high toxicity and, in the absence of a precise sampling program, it was a year of crises. Although the Department of Marine Resources laboratory was able to handle these crises, this method of monitoring toxicity levels was not a responsible one for protecting public health. Further, the lack of detailed information on the toxic areas required large-scale closures to ensure adequate protection.

Late in 1974 funding was obtained from the New England Regional Commission to develop a shellfish monitoring program in Maine. A greatly expanded program was implemented that was patterned after the successful Canadian program and consisted of a series of 18 primary, 35 secondary, and 63 tertiary sampling stations. Once toxicity is established at a primary station, samples are taken at secondary and then tertiary sampling locations. This program has ensured public safety while causing the least disruption to shellfish harvesting activities.

With the experience gained over the years, the sampling program has been modified to make it more appropriate for local conditions. The coast of Maine has been divided into 18 areas from the southwest to the northeast with Area 10 the most southerly and Area 27 in Cobscook Bay the most northerly. At the beginning of a PSP testing year, shellfish samples (mussels, *Mytilus edulis,* and clams, *Mya arenaria)* are collected from each of the 18 areas to determine the background level of the toxin, which at that time of year should be well below quarantine levels. Four or five stations are sampled in each area, usually including the original primary station.

The baseline stations are sampled each week from April to October regardless of the toxicity patterns that are obtained. The stations were established based on historical information, and general trends in toxicity, so decisions on closures are made and the area can be described without having to collect additional samples. Data derived from this monitoring has enabled us to make closures by species, based on the toxin levels in the most sensitive species. For example, during a spring plankton bloom mussels generally become toxic at least a week prior to soft shell clams.

The relatively heavy sampling effort has allowed us to manage shellfish harvesting around PSP closures. In 1979, using information from the sampling program, we were able to keep a portion of Casco Bay open for the first time, with the exception of mussels. Although the area that remained open was relatively small, during the 55-day mussel closure approximately 155 shellfish diggers harvested 17,050 bushels of soft-shelled clams with a 1979 landed value of US$426,259 and an estimated consumer-added value of US$2,770,625 (landed value of US$1,065,648 and estimated consumer-added value of US$6,926,563 in 1997 dollars).

Another area that we manage successfully is Cobscook Bay, adjacent to New Brunswick, Canada. In past years this area has always been closed, but examining the database on this area allowed us to select potentially safe areas for the harvest of clams (mussels cannot be certified as being safe in the summer months). Areas selected for harvesting are sampled twice a week throughout the toxin season. Clam harvesting is an important economic resource in Cobscook Bay, an area of limited economic opportunity, so it is important that the area not be closed unnecessarily.

These are examples of how the data collected over the past 20 years provides insight into how to manage shellfish harvesting areas during toxic algal events. All information from the PSP monitoring program is available from our computer database and can be accessed by date, species, sampling station, and general area of harvest.

For a private aquaculture operation to make use of the information from our monitoring program, it is important to have as much knowledge as possible about the species of shellfish being cultured. In addition to determining the suitability of the local environmental conditions for the culture of a given shellfish species, consideration must also be given to how the species reacts to toxic algae. There are eight species of shellfish that can be cultured in Maine: blue mussel, *Mytilus edulis*; soft-shell clam, *Mya arenaria*; surf clam, *Spisula solidissima;* American oyster, *Crassostrea virginica*; European flat oyster, *Ostrea edulis*; quahog, *Mercenaria mercenaria*; Atlantic scallops, *Placopecten magellanicus*; and Stimpson's surf clams, *Mactromeris polynyma* (an experiment sponsored by the National Science Foundation is underway to assess the aquaculture potential of this species in Maine).

Blue mussels are a high risk species during PSP blooms, accumulating marine biotoxins rapidly and generally depurating relatively quickly as well. Soft-shell clams accumulate and depurate marine biotoxins somewhat more slowly than mussels. Surf clams, a promising new species for aquaculture, accumulate marine biotoxins such as PSP and domoic acid and high levels are depurated very slowly. Quahogs do not accumulate PSP toxins under normal plankton events, but I do not know how quahogs accumulate other marine biotoxins. American oysters do not accumulate PSP toxins and little information is available on their response to other toxins. The observation that quahogs and American oysters do not accumulate PSP toxins can, under suitable regulatory controls, allow them to be marketed during periods of PSP blooms. European flat oysters can become toxic with PSP as rapidly as blue mussels, but there is little information on their response to other toxins. Atlantic scallops accumulate both PSP and domoic acid and depurate slowly. Limited samples from commercial landings have demonstrated that scallops remain toxic all year. Maine allows the landing of only the scallop adductor muscle, which is never toxic. If scallops are to be marketed whole or roe-on, which adds considerably to the value, they must be grown in toxin-free areas.

The development of an economically viable Atlantic scallop culture industry in Maine will require greatly expanded coast-wide monitoring to identify safe areas for culture. The first phase of this expanded monitoring could be conducted during the slack monitoring period from November to April using divers to pinpoint exactly where sampling should be done. Areas with low toxin levels could then be evaluated further.

It is potentially possible, with an amendment of the current regulation, that an aquaculturist may be permitted to market their scallops after lot testing of their whole and roe-on scallop meats as required by the Department of Marine Resources. There is no consideration, however, of lot testing of wild scallops, as the harvest area of landed scallops cannot be determined.

It must be understood that all regulatory standards for marine toxins must be complied with. Shellfish consumers assume that marine toxins are not present; therefore shellfish should have as near a zero toxin level as possible.

The PSP standard of 80 μg per 100 g of edible tissue is based upon Canadian observations made in the 1940s. During the early PSP sampling years, a toxin level of 80 μg/100g (400 mouse units) at a primary sampling station, indicated that toxin levels will rise in adjacent clam harvesting areas within a week to 10 days. This allowed for sufficient time to make safe closures under the administrative procedures in place at that time. Studies in Maine indicate that the time frame for a rise of PSP toxins is variable and is dependent upon the size and location of algal blooms in a given year. Closures are now made as toxin levels approach 80 μg and this regulatory standard has a good record in protecting public health.

The domoic acid standard of 20 ppm is based upon toxin levels observed during the 1987 toxin event in Prince Edward Island. Testing for domoic acid is easily accomplished, but requires expensive analytical equipment. Methods to detect DSP toxin are still under development, so currently the administrative toxin level standard is zero and can be expected to remain at that level indefinitely due to testing difficulties. I expect DSP will be the next crisis toxin for the mussel industry as the species of algae that produce this toxin are present in Maine waters.

Maine's shellfish industry is based upon a publicly-owned resource with limited aquaculture lease sites (most for the bottom culture of blue mussels and oysters). The state is responsible for evaluating all harvest areas for their safety and all tests for marine toxins are conducted by the state. The aquaculture industry submits samples for testing upon request. The industry is informed of the test results but all decisions as to shellfish safety are made by the state. This means that even though samples from an aquaculture site test safe, the lease area may remain closed because adjacent areas are toxic. Under the present monitoring program, Maine cannot certify the safety of these aquaculture sites. It is likely that the monitoring plan now in place is the most cost-effective and reasonable for public safety.

Aquaculturists should determine which portion of the market they wish to occupy. For example, year-round operation may require several lease sites in order to ensure that product will always be available from a safe area. Aquaculturists are apt to find that areas that are toxic seasonally produce high quality mussels during the times when the toxins are not present. In some markets, the seasonal sale of product will be the most satisfactory, using shellfish from areas that are expected to be toxin-free at certain times of the year. If Maine's biotoxin monitoring plan for PSP is used as a example, then late fall to early spring can be expected to be PSP-free.

My experience with marine biotoxins, admittedly, is for the most part limited to PSP. There is some information available on domoic acid from the monthly samples taken from the primary stations during the PSP sampling season and analyzed by a Food and Drug Administration (FDA) laboratory. To date, low positive domoic acid scores have been observed in mussels in eastern Maine at the same time the toxin was found in nearby Canadian waters (late summer). None of the scores have been high enough to require a closure. However, Maine has had two small closures in the fall season because sampling was inadequate to produce timely results. This concept should be considered any time information is unavailable as to the toxin makeup of a harvest area. As soon as information is known, clean areas can safely be reopened.

The aquaculture industry must understand that, while there is a reasonable amount of knowledge available concerning known biotoxins, there are also new toxins that can cause trouble. Aquaculturists are apt to be the first to recognize, from unexplained illnesses, that a new toxin is causing problems (this is known as a human bioassay). When there is any doubt as to the safety of a product, it should always be regarded as unsafe and immediately removed voluntarily from the market. It is assumed that the aquaculture producer will be in contact with the shellfish control agency so that formal action can be taken if a problem is suspected. This is the time and place for the industry to ask for and receive aid from the shellfish control agency in determining when their shellfish are safe. Under HACCP and all related food and drug laws, persons selling shellfish are responsible for the safety of their product.

The information gained from the monitoring of shellfish for PSP along the coast of Maine can give aquaculturists a reasonable prediction of the PSP risk of a location selected for shellfish culture. Other PSP monitoring plans may similarly aid in the selection of culture sites. However, there is insufficient information on other known marine toxins in Maine to provide good predictive indications of site suitability.

To ensure public safety, shellfish aquaculture is strictly regulated with regard to biotoxins. While harvesting of shellfish may be halted during toxic algae blooms, most species depurate after the bloom is over.

Utilization of data generated from a PSP monitoring program will give, with limitations, a rough prediction of when toxin events may be expected to occur. For the regulatory agency, this makes it possible to develop monitoring plans. Industry can develop marketing plans around these toxic events. Ideally the shellfish aquaculturist selects a location based upon the best information available on good growing areas as well as expected PSP levels. It is reasonable to contact the control agency for this information.

Maine has started a Marine Phytoplankton Monitoring Program, which is funded in part by the FDA. This new program is being conducted by the Maine Department of Marine Resources and the University of Maine Co-operative Extension. Twenty volunteer groups work coastwide, with equipment furnished by the program, are collecting and examining plankton collected at the primary PSP sampling stations. It is hoped that in future years the information being generated by this study will aid in a better understanding of toxic algal blooms.

Plankton monitoring as a part of a toxic shellfish program has been common in Europe and Japan for many years and they have had some success in predicting toxic events. This monitoring concept is in its infancy in the United States and Canada. I must encourage aquaculturists to take advantage of any trade associations that offer help in identifying potentially toxic algae in their leases. This information will aid in the management of shellfish and finfish leases. It takes little training for an individual to collect samples and use a microscope to identify algae of interest. I am sure that this concept will pay big dividends in the future.

Preliminary discussions are underway with the Maine Aquaculture Association to enlist several fish farmers in plankton monitoring at their leases. A leading mussel farm also has a biologist on staff who has an interest in plankton monitoring.

In closing, I must point out that Maine's PSP program is based upon the Canada's PSP monitoring program. While the program in Canada is not as extensive as that in Maine, the information being generated by the Canadian Food Inspection Agency can be used by the aquaculture industry in determining where to situate shellfish operations.

John W. Hurst Jr. is with the Maine Department of Marine Resources, Marine Resources Laboratory, West Boothbay Harbor, Maine, USA 04575

Les écloseries de mollusques bivalves: mode d'emploi

Marcel Le Pennec

Largement représentés à travers le monde et possédant un fort intérêt économique les mollusques bivalves marins comptent dans le commerce des produits aquacoles de nombreux pays. Cependant, ce n'est qu'à partir des années 1970 que l'aquaculture de quelques espèces a permis à cette activité halieutique d'acquérir les signes extérieurs d'une existence bien établie. Inspirées par les travaux de recherche en laboratoire de quelques pionniers, dont Loosanoff (USA), Walne (GB) et Imai (Japon), des méthodes expérimentales permettant l'élevage de plusieurs espèces de bivalves ont été mises au point et de nombreuses écloseries de production ont ainsi pu voir le jour un peu partout dans le monde. Certaines ont eu une existence brève, d'autres un peu plus longue, mais rares sont celles qui, comme la F. Flowers (USA), la Seasalter Shellfish (GB) et la SATMAR (F), sont encore opérationnelles. Au cours de la précédente décennie la création de ces auxiliaires de productions conchylicoles s'est encore accélérée, mais le bilan, à quelques exceptions près, est loin d'être satisfaisant. L'actuelle génération d'écloseries, construite durant la présente décennie, souffre toujours de mêmes symptômes que leurs aînées et rares sont celles qui peuvent répondre à leur objectif premier: produire régulièrement des larves de qualité en nombre suffisant. En prenant l'exemple des pectinidés sur lesquels plusieurs pays comme le Canada, le Chili, la France, etc., fondent beaucoup d'espoirs pour leur économie aquacole, nous tenterons d'analyser l'origine des fluctuations annuelles enregistrées dans les résultats des écloseries, incompatibles avec l'exigence des marchés nationaux et internationaux. Ces constatations suscitent des interrogations et des réflexions de la part des écloseurs et des scientifiques sur les paramètres externes ou internes, non encore maîtrisés, qui permettraient de régulariser et d'améliorer les rendements de production. Il semble cependant que parmi tous ces facteurs exogènes ou endogènes, la qualité de l'alimentation des géniteurs en conditionnement soit considérée prioritairement car elle affecte directement la constitution des gamètes et le développement larvaire. C'est une des voies essentielles sur lesquelles se focalisent les recherches actuelles, même si en parallèle la biologie, la biochimie, la physiologie de la reproduction ainsi que la pathologie des adultes et des larves sont également l'objet d'études approfondies.

Introduction

C'est sur la base des travaux de quelques scientifiques[1-3] qui ont mis au point des méthodes expérimentales reproductibles d'élevages larvaires de mollusques bivalves que des écloseries ont été créées, un peu partout dans le monde, depuis une trentaine d'années. L'objectif de ces unités de production est *a priori* simple: il s'agit d'assurer une reproduction contrôlée de quelques espèces d'intérêt économique pendant la majeure partie de l'année.[4] Cependant, la période de reproduction étant brève dans la nature, 1 à 2 mois par an, ceci oblige à préparer des géniteurs à élaborer des gamètes en dehors de ces périodes en pratiquant leur conditionnement. Une fois la reproduction assurée commence alors l'élevage larvaire qui dure de 10 à 20 jours. Pour quelques espèces élevées c'est au stade pédivéligère que se font les premières ventes aux aquaculteurs. Pour la majorité des espèces la métamorphose est assurée par l'écloseur qui élève son naissain en eau de mer contrôlée, chauffée et enrichie en nourriture, avant de le transférer, entre 1 et 2 mm, dans une structure transitoire, la nurserie. Il y séjourne encore de quelques semaines à quelques mois afin d'être prégrossi jusqu'à une taille suffisante, de 6 à 8 mm, qui lui permet de s'adapter à un environnement fluctuant et aux prédateurs dans des conditions satisfaisantes.

Les espèces cibles retenues dans les écloseries de production appartiennent essentiellement à quatre familles de bivalves, celle des ostréidés: *Crassostrea gigas* (USA, France, Grande-Bretagne), *Crassostrea virginica* (USA, Canada), *Crassostrea sikamea* (USA), *Ostrea edulis* (France, USA, Canada), *Ostrea conchapila* (USA), *Ostrea lurida* (USA), celle des pectinidés: *Pecten maximus* (France), *Pecten fumatus* (Australie), *Mizuhopecten yessoensis* (Japon, Canada), *Argopecten irradians* (USA, Chine) *Argopecten purpuratus* (Chili), *Placopecten magellanicus* (Canada), *Chlamys farreri* (Chine), *Chlamys asperrimus* (Australie), *Chlamys bifrons* (Australie), celle des vénéridés: *Ruditapes philippinarum* (France, Grande Bretagne, Espagne, Irlande, USA), *Ruditapes decussatus* (France, Tunisie), *Mercenaria mercenaria* (USA), celle des mytilidés: *Mytilus edulis*, *Mytilus galloprovincialis* et *Mytilus trossulus* (USA).

Des essais prometteurs sur *Panopea abrupta* ("geoduck clam"), appartenant à la famille des myidés, sont en cours aux USA (État de Washington).

Ecloseries et Rentabilité

Les écloseries de production de mollusques ont en général une existence brève et rares sont celles qui, comme la Seasalter Shellfish (Grande-Bretagne) et la SATMAR (Société Atlantique de Mariculture, France) sont encore performantes après plus de 25 ans de fonctionnement, la plus ancienne au monde étant vraisemblablement la F. Flowers à Long Island (USA) qui date de 1967. La plus grosse écloserie est la Coast Seafoods Company (USA). De 1,1 milliard de larves qu'elle était en 1979, sa production est passée à 27,9 milliards de larves en 1994. Chaque année, un peu partout dans le monde, de nombreuses écloseries se ferment tandis que d'autres s'ouvrent. Comme il s'agit le plus souvent d'entreprises commerciales, il est extrêmement difficile d'avoir connaissance de leur bilan annuel et de leur niveau de rentabilité.

Il y a une dizaine d'années, les seules écloseries rentables étaient :

- celles qui, aux USA, produisaient du naissain (*C. virginica*) pour leur propre compte, assurant ensuite le grossissement des animaux sur leurs propres parcs jusqu'à leur taille marchande;
- celles qui, aux USA, vendaient leur produit (*C. gigas*) uniquement aux stades oeillée ou pédivéligère, expédiés humides dans des conteneurs réfrigérés chez les aquaculteurs.[4]

Il semble qu'actuellement, ce soit encore la réalité dans le monde des écloseries.[5]

Ecloseries de Pectinidés

En raison de nombreux problèmes qui se posent dans l'élevage larvaire et post-larvaire des pectinidés nous analyserons particulièrement cette filière de production plutôt que celle des ostréidés ou des vénéridés.

Dans de nombreux pays comme le Canada, le Chili, la France, etc., les pectinidés comptent parmi les principaux produits aquacoles dans leur économie de la mer et, face à la menace d'effondrement des bancs naturels des espèces autochtones : *Placopecten magellanicus* (Canada), *Argopecten purpuratus* (Chili), *Pecten maximus* (France), diverses mesures ont été instaurées pour enrayer ce phénomène et permettre un développement de leur aquaculture.[6] Les principales mesures adoptées vont d'une gestion rigoureuse des pêches au captage naturel de naissain et/ou sa production en écloserie. Dans le tableau 1 figurent les principaux pays aquacoles où l'exploitation commerciale des Pectinidés a motivé la construction d'écloseries, les espèces retenues et leur statut actuel.

La première grande écloserie de Pectinidés a été construite au Japon en 1969, sur le bord de la baie de Mutsu (Préfecture d'Aomori), mais la mise au point d'une technique performante de captage de naissain en mer a décidé les Japonais à privilégier cette méthode au détriment de l'écloserie.

En France, comme au Canada, au Mexique, en

Tableau 1. Principaux pectinidés élevés au monde et état actuel de leur aquaculture.

Pays	Espèces	État actuel de leur aquaculture	Référence
Canada	*Placopecten magellanicus* côte est	Production de naissain irrégulière depuis 1986.	8, 22
	Mizuhopecten yessoensis côte ouest	Écloseries semi-privées depuis 1989. Augmentation régulière de la production de naissain. Objectif : 80.10^6 naissains/an. Mortalités postlarvaires importantes dues à la prédation par *Pseudostylachus ostreaphagus*.	24, 25
U.S.A.	*Argopecten irradians* côte est	Nombreuses écloseries.	26
	Crassodoma gigantea côte ouest	Essais expérimentaux concluants.	27, 28
Mexique	*Argopecten ventricosus* et *Lyropecten subnodosus*	Développement réussi en laboratoire depuis 1992 pour la 1ère espèce et 1994 pour la deuxième. Ecloserie commerciale (CREMES/Etat de Sonora) produit du naissain de *L. subnodosus*, mais taux de mortalité élevé.	29
Chili	*Argopecten purpuratus*	Essais expérimentaux de 1979 à 1984. Plusieurs écloseries de production depuis cette date, mais résultats fluctuants, non satisfaisants.	6, 30
Japon	*Mizuhopecten yessoensis*	Élevages expérimentaux réussis dès 1985. Des écloseries ont été construites dès 1969 (baie de Mutsu, Aomori). Aucune ne fonctionne en raison des facilités de captage de naissain en mer.	31, 32
Chine	*Chlamys farreri* *Chlamys nobilis* *Mizuhopecten yessoensis* (introduite en 1980) *Argopecten irradians* (introduite en 1982)	De nombreuses écloseries (d'État, Coopératives de pêcheurs, particuliers) se consacrent notamment à la production de *C. farreri* et *A. irradians*. Des mortalités importantes freinent actuellement l'aquaculture de *A. irradians*.	9, 33
Australie	*Pecten fumatus* *Chlamys asperrinus* *Chlamys bifrons* *Amusium balloti*	Pour les 3 premières espèces, productions irrégulières en écloseries, venant compléter le captage en mer. Pour *A. balloti*, production de naissain difficile et irrégulière.	34
France	*Pecten maximus*	Deux écloseries de production (Argenton/ IFREMER; Tinduff/coopérative de pêcheurs). Production de naissain irrégulière, mais en progression : 25.10^6 en 1996 au Tinduff.	35

Australie, etc., le modèle japonais de captage du naissain a été copié avec plus au moins de succès selon les pays. En France, les essais en rade de Brest et en baie de Saint Brieuc ayant été non concluants, c'est l'autre alternative, consistant en la production expérimentale de naissain, qui a été décidée. Ainsi, à partir des années 1980 ce pays, comme le Chili, s'est lancé dans la construction d'écloseries devant fournir du naissain en quantité et en qualité pour assurer le repeuplement et/ou développer une aquaculture extensive. Deux écloseries de production de *P. maximus* fonctionnent depuis une quinzaine d'années à Argenton (unité expérimentale IFREMER) et au Tinduff (comité local des pêches maritimes de la rade de Brest). A partir de 1997 seule l'écloserie du Tinduff continuera la production de naissains de Pectinidés destinés à être cultivés essentiellement en rade de Brest.

Au Chili, les premières écloseries destinées à la production de *A. purpuratus* ont eu une existence brève. A partir de 1990 on assiste à la création d'un réseau recouvrant le nord du pays dont les IIème (Antofagasta – Mejillones), IIIème (Caldéra) et IVème (San José) Régions.[6] La production des écloseries est encore largement insuffisante, et trop variable, pour alimenter les filières d'élevage en extensif et le recours au captage naturel des pédivéligères est complété par une pêche clandestine du naissain.

Au Canada, après de nombreuses tentatives d'élevage de *P. magellanicus* au laboratoire, ce n'est qu'en 1986 que la première production de naissain a été obtenue. Ceci autorisait le développement d'écloseries expérimentales dans de nombreuses provinces maritimes dont Terre-Neuve, la Nouvelle-Écosse, et le Québec.[7,8] Cependant les résultats sont encore modestes et fluctuants.

Malgré les recherches entreprises au cours de ces quinze dernières années pour améliorer ces filières de production intéressantes pour l'économie de ces 3 pays, les résultats obtenus sont infimes par rapport au marché de ces espèces. Par exemple, la France qui consomme 50 à 60 000 t de *P. maximus* annuellement n'en produit que 50 t par aquaculture. Une production accrue de naissain (25.10^6 en 1996) à l'écloserie du Tinduff laisse cependant prévoir que dès 1998/99 ce seront 250 t qui seront récoltées,[9] mais ceci restera encore infime par rapport à la demande.

Ainsi, après plus d'une décennie de pratique, les résultats obtenus sont intéressants sur le plan fondamental car ils permettent de mieux connaître la biologie et l'écophysiologie des espèces-cibles, mais insuffisants du point de vue économique en raison des fluctuations de la production de naissain et de la faible valeur marchande, sur le marché mondial, de certains Pectinidés qui concurrencent les espèces locales.

En ne tenant compte que de ces 3 pays les résultats obtenus tant en écloserie expérimentale que commerciale montrent donc d'importantes fluctuations annuelles incompatibles avec l'exigence des besoins économiques et qui traduisent la difficulté de maîtrise des écloseries.

Paramètres à Considérer

A l'heure actuelle il n'existe aucune écloserie capable de réussir à 100% un élevage larvaire, quelle que soit l'espèce de bivalve considérée.

Comment interpréter la variabilité des résultats obtenus au cours d'une année et la non-reproductibilité des bons résultats obtenus d'une année sur l'autre? Les quelques résultats d'exploitation d'écloseries commerciales dont nous disposons montrent que la production de larves, cumulée sur quelques années, suit une courbe d'allure sigmoïde.[6] Certaines époques de l'année semblent plus favorables que d'autres à la production larvaire mais il arrive fréquemment que le cycle d'élevage soit interrompu avant ou après la métamorphose pour des raisons diverses.

Les recherches entreprises tant dans les laboratoires expérimentaux que dans les écloseries de production pour comprendre les fluctuations des résultats obtenus font ressortir l'action de multiples facteurs allant de la zootechnie à la biologie des espèces et à leur milieu environnant. Il est cependant impossible de hiérarchiser les différents facteurs intervenant sur les résultats obtenus en raison de la multiplicité de ces facteurs propres à chaque site d'élevage et à chaque espèce.

Au début de la précédente décennie, les problèmes qui se posaient dans les écloseries commerciales construites entre 1970 et 1980 étaient de trois ordres: génétique (origine des géniteurs, sélection, cytogénétique, consanguinité, etc.) écophysiologique (conditions d'élevage = eau, température, nourriture), écophysiologie larvaire (pathologique = bactéries).[10] Après enquête auprès de 11 écloseries situées aux USA, au Japon, en Grande-Bretagne, et en France, Lucas[10] concluait que "du côté des écloseries, la crainte majeure est de voir les élevages disparaître sous l'effet d'une attaque bactérienne, ce sont donc les problèmes de pathologie qui apparaissent comme primordiaux. Viennent ensuite les préoccupations d'ordre écophysiologique tandis que la génétique est rarement prise en compte".

À la fin de la précédente décennie les principaux problèmes rencontrés dans les écloseries concernent essentiellement le choix des sites d'installation, la conception et l'entretien de l'outil de production, la méconnaissance des phénomènes biologiques mis en cause dans le milieu marin (et notamment la pathologie) et l'inadaptation du produit par rapport à la demande de la profession.[5]

Il existe souvent un décalage entre les raisonnements des scientifiques et ceux des écloseurs concernant l'action des facteurs responsables des fluctuations des résultats obtenus dans l'aquaculture des bivalves. Tous sont cependant d'accord pour considérer certains problèmes comme cruciaux, comme par exemple la nocivité de bactéries. Ce constat, déjà ancien (ref. *in* Lucas[10]) est encore d'actualité et rares sont les écloseries qui, à un moment de leur existence, n'ont pas eu à résoudre cet épineux problème. Ainsi par exemple, les élevages de Pectinidés sont parfois victimes d'attaques foudroyantes de bactéries pathogènes. Une étude récente montre qu'en l'absence d'antibiotiques des larves de *P. maximus* sont fréquemment victimes de vibrioses surtout entre le 14ème et le 20ème jour d'élevage.[11] Douze souches bactériennes ont été isolées des larves moribondes de ce bivalve dont une est particulièrement virulente: *Vibrio scala.* Elle agit par l'intermédiaire d'une toxine, un peptide de faible poids moléculaire (< 1 KD) qui lyse les hémocytes des larves et provoque ainsi leur mort.[11]

En dehors des problèmes de pathologie larvaire le conditionnement des adultes fait l'objet de recherches attentives puisque cette opération doit aboutir à la production de gamètes de bonne qualité cytostructurale[12] et biochimique.[13]

Dans toutes expériences de conditionnement le facteur trophique est important à considérer puisque l'alimentation des géniteurs est responsable non seulement de la constitution des gamètes et de la phase endotrophe larvaire, mais a aussi vraisemblablement des répercussions sur les étapes ultérieures de l'élevage, dont la métamorphose. L'étude des microalgues utilisées pour la nourriture des géniteurs en maturation expérimentale montre que leur composition en acide gras varie selon les espèces et les conditions de culture. Or certains de ces acides gras sont essentiels pour la constitution des membranes des ovocytes et des larves.[13-15] Ainsi les acides gras polyinsaturés comme le 20:4 (n-6) et le 22:6 (n-3), qui doivent être abondants et indispensables dans les ovocytes de *P. maximus*, doivent provenir de l'aliment fourni puisque chez les Mollusques les capacités de biosynthèse de ces acides gras sont faibles.[13]

Parmi les autres molécules essentielles au bon développement larvaire, il faut mentionner les vitamines et les oligo-éléments, composés pour lesquels les recherches ne progressent que lentement.[16]

Un autre paramètre important à considérer concerne la biologie de la reproduction. Les données que nous possédons sur cette importante fonction sont encore fragmentaires, notamment en ce qui concerne les mécanismes endogènes qui interviennent, et l'action de certains facteurs de l'environnement. Ainsi il est impératif de connaître la rythmicité du cycle sexuel puisqu'on a montré l'existence d'une période de l'année plus favorable à la production de gamètes de qualité, par exemple en fin d'hiver – début printemps pour *P. maximus*[6] et *A. purpuratus*.[17] En dehors de ces périodes les productions sont aléatoires, même si les méthodes utilisées par les écloseurs restent identiques. C'est donc vraisemblablement dans les individus que des modifications interviennent, agissant sur leur comportement reproducteur et la qualité des gamètes fournis.

Pour tenter de mieux comprendre le processus reproducteur, diverses pistes sont expérimentées dans des stations de terrain et des écloseries (ex: Tinduff, rade de Brest) et des comparaisons sont établies avec le milieu naturel.

L'une de ces pistes est la désaisonnalisation des géniteurs qui a pour but, en faisant jouer deux facteurs abiotiques, la température et la photopériode, d'obtenir une "mise en veille" de l'activité gonadique.[18] Celle-ci peut être levée à n'importe quel moment par une modification inverse de ces deux facteurs, l'objectif de ces recherches étant de parvenir à disposer, à tout moment de l'année, d'un stock d'individus en état physiologique optimum pour débuter leur conditionnement.

Une autre voie de recherche prend en compte les amines biogènes impliquées dans la régulation du cycle de reproduction. Chez *M. yessoensis*,[19] *A. irradians*,[20] et *P. maximus*,[21] on a montré l'existence de rythmes physiologiques internes et des déclencheurs induisant des orientations irréversibles du cycle de reproduction (mobilisation des sucres, maturations ovocytaires, déclenchement d'émissions gamétiques, etc.). Cette connaissance est essentielle pour pouvoir agir expérimentalement, par injection de molécules médiatrices, sur certaines phases du cycle sexuel.

Comment Réussir une Écloserie de Bivalves ?

Il n'existe pas de formule magique permettant de réussir à coup sûr l'élevage de telle ou telle espèce de bivalves tant les paramètres à considérer sont nombreux. Cependant, les recherches entreprises au cours de la précédente décennie, notamment sur les Pectinidés, qui peuvent être rangés parmi les bivalves difficiles à élever, débouchent sur des résultats intéressants. Ceux-ci constituent autant de pistes à suivre pour améliorer le fonctionnement des écloseries.

Parmi les principaux facteurs à considérer figurent :

- ***La qualité des sites.*** Les sites potentiels les plus propices aux activités aquacoles sont, notamment en Europe, très souvent convoités par d'autres activités marines (industrie, plaisance, etc.). La qualité de l'eau, souvent menacée par des actions anthropiques (effluents agricoles, urbains, etc.), doit être irréprochable et constante au cours du temps.
- ***La technologie.*** C'est un aspect important où l'adéquation entre la conception et le fonctionnement de l'outil et le personnel doit être parfaite. La surface disponible doit être grande et le personnel varié.
- ***Le conditionnement des géniteurs.*** La variabilité de la composition biochimique des microalgues est encore sous-estimée en écloserie. A court terme l'incorporation d'acides gras polyinsaturés et autres molécules essentielles (oligo-éléments, vitamines, etc.) dans les régimes nutritionnels larvaires est envisageable par la sélection de nouvelles algues-fourrages et/ou la mise au point de micro-capsules alimentaires. A court terme également l'application des résultats des recherches concernant les rythmes internes des cycles sexuels et des molécules médiatrices de ces cycles devrait améliorer les performances de la reproduction.
- ***La pathologie larvaire.*** C'est un problème important qui a pu être solutionné, à l'occasion, par l'adjonction systématique d'antibiotiques, dont le chloramphénicol, dans les eaux d'élevage larvaire. En Europe la législation interdit désormais son utilisation or, jusqu'à présent, aucun élevage de *P. maximus* n'a pu être réalisé sans antibiotique. Une des mesures préconisées pour éviter les proliférations bactériennes est de diminuer la densité des larves en élevage. La recherche de bactéries probiotiques, capables d'occuper l'environnement larvaire et d'empêcher le développement de souches pathogènes est d'actualité.
- ***L'élevage de plusieurs espèces.*** Miser sur la production d'une seule espèce est, sauf cas exceptionnel, une erreur. En Europe, les écloseries qui fonctionnent bien au point de vue économique, comme la Seasalter Shellfish et la SATMAR, produisent dans l'année du naissain de *Ruditapes philippinarum, Crassostrea gigas, Ruditapes decussatus* et *Ostrea edulis*. Aux USA, la Taylor United Inc. (État de Washington) est aussi une écloserie plurispécifique produisant selon les saisons du naissain de *Mytilus galloprovincialis, Crassostrea gigas, Crassostrea sikamea, Ostrea lurida, Ruditapes philippinarum* et *Panopea abrupta*.[23] Ces élevages doivent se faire sur plusieurs sites.
- ***Une production intégrée.*** Il est important de pouvoir disposer de parcs de prégrossissement et de grossissement capables de recevoir le naissain issu de l'écloserie-nurserie. Ainsi, par exemple la Coast Seafoods Company possède 720 ha de parcs d'ensemencement de naissain.[24] En outre les parcs sont des auxiliaires indispensables permettant de réguler la production en cas de non compatibilité entre l'offre et la demande.
- ***L'élaboration d'un produit de qualité supérieure à celle du milieu naturel.*** L'exemple le plus éloquent dans ce domaine est la triploïdie, qui permet de créer en écloserie un produit inexistant dans la nature et qui sort donc du contexte concurrentiel classique. Cet

intérêt pour la triploïdie est accompagné de nouvelles réflexions et d'expérimentations, de la part des scientifiques et des écloseurs, sur la sélection génétique des individus reproducteurs. Trop souvent délaissé en écloserie, cet axe de recherche doit permettre de sélectionner des individus performants, capables de résister aux infections bactériennes ou virales, de croître rapidement, et de fournir aux consommateurs un produit attractif où certaines qualités (forme de la coquille, couleur du manteau et de la coquille, importance du muscle, etc.) seront valorisées.

L'auteur adresse ses plus vifs remerciements à Yves Le Borgne (SATMAR, Barfleur, France) pour l'aide apportée à la réalisation de cet article ainsi qu'à André Mallet (Dartmouth, Canada) pour les informations sur l'aquaculture au Canada.

Références

1. Loosanoff VR, Davis HC. 1963. *Adv. Mar. Biol.* 1:1-136.
2. Walne P. 1996. *Fish. Inv. Ser.* 2:1-53.
3. Imai T. 1950. *Tohoku J. Agric. Res.* 1:69-86.
4. Le Borgne Y. 1986. In, *Aquaculture* (G Barnabé, ed) p.273-284. Lavoisier, Paris.
5. Le Borgne Y. SATMAR. Com. pers.
6. Le Pennec M., Avendaño M, Robert R, Moraga D. 1997. *J. Med. Appl. Malacol.* (in press).
7. Naidu KS, Fournier R, Marsot P, Worms J. 1989. In, *Cold Water Aquaculture in Atlantic Canada* (A Boghen, ed) p. 211-239. The Canadian Institute for Research on Regional Development, Moncton.
8. Naidu KS. 1991. In, *Scallops: Biology, Ecology and Aquaculture* (S Shumway, ed), p. 861-897. Elsevier, Amsterdam.
9. Dao JC. IFREMER. Com. pers.
10. Lucas A. 1981. *Océanis* 5:511-533.
11. Lambert F, Nicolas JL, Cilia V, Corre S. 1997. *Int. J. Syst. Bacteriol.* 48(2):481-487.
12. Dorange G. 1989. *Th. Doct. Univ. UBO. Brest*, 133 p.
13. Soudant P. 1995. *Th. Doct. Univ. UBO. Brest*, 294 p.
14. Delaunay F. 1992. *Th. Doct. Univ. UBO. Brest*, 201 p.
15. Samain JF, Soudant P, Marty Y, Le Coz JR, Séguineau C, Moal J. 1995. *Rade Inf'Eaux, Brest* 6:16-18.
16. Séguineau C, Lashi-Loquerie A, Leclerc M, Samain JF, Moal J, Fayol V. 1995. *J. Mar. Biotech.* 1:67-71.
17. Avendaño M, Le Pennec M. 1997. *Aquacult. Res.* 28:175-182.
18. Paulet YM, Saout C, Donval A, Bekhadra F, Casse N, 1996. *Rapp. Int. Contrat de Baie, IEM-CUB*, 12 p.
19. Osada M, Nomura T. 1989. *Comp. Biochem. Physiol.* 2:349-353.
20. Martinez G, Rivera A. 1994. *Invert. Reprod. Dev.* 2:167-174.
21. Paulet YM, Bekhadra F, Devauchelle N, Donval A, Dorange G. 1997. *An. Inst. Oceano.* (in press).
22. Couturier C, Dabinett P, Lanteigne M. 1995. In, *Cold Water Aquaculture in Atlantic Canada* (A Boghen, ed) p. 297-340. The Canadian Institute for Research on Regional Development, Moncton.
23. Davis JP. Taylor Resources Shellfish Hatchery. Com. pers.
24. Robert R. 1994. *Equinoxe* 50:19-31.
25. Bourne N. 1997.Unpublished data (Abstract of the 11th Int. Pectinid Workshop, La Paz, Mexico, p. 37-39).
26. Rhodes E. 1991. In, *Scallops : Biology, Ecology and Aquaculture* (S Shumway, ed), p. 913-942. Elsevier, Amsterdam.
27. Leighton DL, Phleger CP. 1977. *Proc. World Maricul. Soc.* 8:457-469.
28. Bourne N. 1991. In, *Scallops: Biology, Ecology and Aquaculture* (S Shumway, ed), p. 925-942. Elsevier, Amsterdam.
29. Serrano Guzman S, Robles Mungaray M, Velasco Blanco G, Voltolina L, Hoyos Chairez F. 1997.Unpublished data (Abstract of the 11th Int. Pectinid Workshop, La Paz, Mexico, p. 25-27).
30. Disalvo L, Alarcon E, Martinez E, Uribe E. 1984. *Rev. Chil. Hist. Nat.* 57:35-45.
31. Doumenge F. 1986. In, *Aquaculture* (G Barnabé, ed) p. 822-954, Lavoisier, Paris.
32. Ito H. 1991. In, *Scallops: Biology, Ecology and Aquaculture* (S Shumway, ed), p.1017-1055. Elsevier, Amsterdam.
33. Luo Y. 1991. In, *Scallops: Biology, Ecology and Aquaculture* (S Shumway, ed), p.809-824. Elsevier, Amsterdam.
34. Gwyther D, Cropp DA, Joll LM, Dredge MC. 1991 In, *Scallops: Biology, Ecology and Aquaculture* (S Shumway, ed), p. 835 -851. Elsevier, Amsterdam.
35. Le Pennec M, Robert R, Avendaño M. 1998. *J. Shellfish Res.* 17 (in press).

Dr. Marcel LePennec, Professeur, Biologie Marine, UMR CNRS 6539, Institut Universitaire Européen de la Mer, Université de Bretagne Occidentale, 29280 – PLOUZANÉ, France.

Calendar

•**Annual Meeting of the American Fisheries Society,** 23 – 27 August 1998, Hartford Civic Center and Sheraton Hotel, Hartford, CT, USA. Scientific presentations and plenary speakers will explore the theme *Challenges for the New Millenium: Shaping the Future of Fisheries Science and the Fisheries Profession.* AFS web site: http://www/ esd.ornl.gov/societies/ AFS/annual98/index.html.

•**Coastal Zone Canada '98 (CZC '98),** 30 August – 3 September 1998, Victoria, BC. Theme: *Coastal Communities in the 21st Century, Sharing our Experience, Building our Knowledge.* Information: http://www. ios. bc.ca/ios/czc98/; e-mail czc 98@ ios.bc.ca; telephone 250 721-8746; fax 250 721-8774.

•**3rd International Symposium on Aquatic Animal Health**, 30 August – 3 September 1998, Renaissance Harborplace Hotel, Baltimore, Maryland, USA. Scientific sessions, including plenary lectures and contributed oral and poster presentations. Symposium office: Division of Comparative Medicine, Johns Hopkins University School of Medicine, 720 Rutland Avenue, Baltimore 21205 (telephone 410 955-3273; fax 410 550-5068).

•**British Trout Farming Conference**, 2 – 4 September 1998, Sparsholt College, Winchester, Hampshire, England. Topics: Abstraction and Discharge, Alarm Systems, Fish Production with Little Water; Exotic Imports of Fish, Options for Feed Ingredients, Vegetable Oils in Fish Feeds, Omega 3 Oils and Human Health, Marketing Fish, Eels, Sea Bass and Sea Bream, Organic Farming, Pigmentation of Feeds, and Diseases/Treatments Update. Despite its increasing size, this event has retained an informal atmosphere and is an ideal environment for fish farmers, scientists, administrators, and service and supply companies to meet and exchange ideas.Information: Shaun Leonard, Conference Organizer (telephone 44 1962 776441; fax 44 1962 776587; e-mail enguiry@sparsholt.ac.uk).

•**9th International Symposium on River and Lake Environments (ISRLE '98),** 8 – 12 September 1998, Hongshan Hotel, Wuhan, China. Symposium language is English. Post-symposium tour to Huangshan (the Yellow Mountains). Symposium Secretary: Prof. Dr. XIE Ping, Institute of Hydrobiology, Chinese Academy of Sciences, Wuhan 430072, China (telephone 86 27 7647703; fax 86 27 7875132; e-mail isrle98@ lily.whihb.ac.cn). Abstract deadline: 20 June. Topics: Population and Community Ecology of Aquatic Plants and Animals, Environmental Biology, System Ecology in Inland Waters, Fishery ecology and Management, Ecological Studies and Conservation of Wetlands, Status and Conservation of Biodiversity in Inland Waters, Impacts of Dam Construction on River and Lake Ecosystems.

•**AQUAEXPO 98**, a seafood show and international fair of supplies, technology and services for the aquaculture and fishing industry. 22-22 September 1998, Guayaquil, Ecuador. Organized by the Ecuadorean Chamber of Aquaculture, a private organization that represents the shrimp sector. Information: Ecuadorian Aquaculture Chamber (e-mail cna@gu.pro.ec, fax (593-4) 281741).

•**Aquaculture Europe**, 7 – 10 October 1998, Bordeaux, France. Sponsored by the European Aquaculture Society. Theme *Aquaculture and Water: Fish Culture, Shellfish Culture and Water Usage* was chosen to provide a forum for discussing the achievements and constraints of the management of the aquatic environment, the use of water in fish and shellfish farming, the interactions with other users of water, water quality, etc. Information: EAS, Slijkensesteenweg 4, B-8400 Oostende, Belgium (fax 32 59 32 10 05; e-mail eas@inicall.be).

•**Pacific Aquaculture Exchange, Conference, and Exhibition,** 1 – 2 October 1998, Campbell River, BC. Information: Sydney Jane Brittain, Master Promotions (telephone 506 658-0018, fax 506 658-0750, e-mail show@nbnet,nb.ca).

•**Workshop on Offshore Technologies for Aquaculture,** 13 – 16 October 1998. TECHNION, Technion City, Haifa, Israel. Workshop will bring together farmers, naval architects, ocean engineers, and manufacturers, to identify problems and stimulate researchers and manufacturers to solve them. Another aim is the formation of partnerships to solve specific problems or develop a desired product. Information: Dr. Adrian Biran, Faculty of Mechanical Engineering, TECHNION, Haifa 32000, Israel (telephone 972-4-8292609 or 972-4-8292618, fax 972-4-8324533, e-mail capsd@tx.technicon.ac.il).

•**FISH EXPO Boston,** 15 – 17 October 1998, World Trade Center, Boston, USA. Produced by Diversified Expositions, P.O. Box 7437, Portland, Maine, USA 04112 (telephone 207 842-5508).

•**International Ozone Association, Pan American Group Conference,** 18 – 21 October 1998, Hotel Vancouver, Vancouver, BC. Information: Margit Istok (telephone 203 348-3542, fax 203 967-4845).

•**Aquaculture Brazil '98,** 2 – 6 November 1998, Recife, Brazil. Sponsored by the Latin American Chapter of the World Aquaculture Society, the Brazilian Shrimp Farming Association and the Brazilian Aquaculture Association. Farm tours are being arranged to shrimp hatcheries and farms, tilapia facilities and other areas of interest. Web Site: http://ag.ansc.purdue.edu/aquanic/was/was.htm. Conference information: John Cooksey, World Aquaculture Society, 21710 7th Place West, Bothell, Washington USA 98021 (e-mail worldaqua @aol.com, telephone 415 485-6682, fax 425 483-6319).).

•**2nd International Conference on Shellfish Restoration,** 18-22 November, Crowne Plaza Resort, Hilton Head, South Carolina. Conference will consist of invited and contributed oral and poster presentations and workshops. A session will also be organized by the Oyster Disease Research Program. The mornings will feature internationally recognized plenary speakers and the afternoon will feature concurrent sessions organized around theme areas. Registration information: Elaine Knight (e-mail knightel@musc.edu, fax 803 727-2080). To submit an abstract contact Rick DeVoe (e-mail devoemr@musc.edu, fax 803 727-2080). Updated information available at http://www.csc.noaa.gov/SCSeaGrant/text/CSR.html.

•**Northeast Aquaculture Conference and Expo,** 18 – 19 November 1998, Samoset Resort, Rockport, Maine. Event will showcase developments in aquaculture production and research in the Northeast. It will be followed by a 1-day "Industry Summit" on November 20. Information: Sydney Jane Brittain (telephone 506 658-0018; fax 506 658-0750, e-mail show@nbnet.nb.ca).

•**Fish Expo Seattle,** 19 – 21 November 1998. Washington State Convention and Trade Center, Seattle. Information: Diversified Expositions (telephone 207 842-5508).

•**Marketing and Shipping Live Aquatic Products '98**, 2nd International Conference and Exhibition, 22 – 24 November 1998, Marriott Hotel, Sea-Tac Airport, Seattle, Washington, USA. Aims to assist fishers, growers and marketers of aquatic products in supplying the expanding market while complying with increasing regulations. Focus is on ornamentals, baits, finfish, shellfish, plants, and aquatic foods. Major topics: resources, shipping, research, environmental, harvesting, physiology, exotics, sociological, holding, reconditioning, regulations, political issues, packaging, marketing, water quality, and humanitarian issues.

Conference manager: John Peters, Nor'Westerly Food Technology Services, 20455 – 1st Ave NE, Suite 303, Poulsbo, WA 98370-9329 USA (fax 360 394-3760; e-mail JohnBPeters@compuserve.com).

•**Canadian Conference for Fisheries Research (CCFFR),** 8-10 January 1999, Edmonton, Alberta. Major themes: Effects of Land Use on Stream Fish and their Habitat, Impacts of Endocrine Disruptors and Contaminants, Changes in Climate and Ecosystems, Innovative Applications of Genetics in Fishery Management. Deadline for abstracts: 11 September. Submit abstracts to the program chair: Dr. Dick Beamish, Pacific Biological Station, Nanaimo, BC V9R 5K6. For general information contact the Dr. Howard Powles at powlesh@dfo-mpo.gc.ca or the CCFR web site at http://www.phys.ocean.dal.ca/ccfr/index.html.

•**Aquaculture America '99,** 27 – 30 January 1999, Tampa, Florida, USA. Meeting of the US Chapter of the World Aquaculture Society, the National Aquaculture Association, and and the US Suppliers Assocation. Also involved are the American Tilapia Association, Striped Bass Growers Association, and the Florida Aquaculture Association. Abstracts due 31 July 1998. Information: John Cooksey, Conference Manager, 21910 7th Place West, Bothell, Washington (telephone 425 485-6682, fax 425 483-6319, e-mail worldaqua@ aol.com).

•**Annual Meeting of the National Shellfisheries Association,** 18 – 22 April 1999, Westin Hotel, Halifax, Nova Scotia, Canada. Special sessions: Modelling Shellfish Ecosystems; Science, Business, and the Future of the Shellfisheries Industry; Physiological Ecology of Shellfish; Applications and Future Directions, Perspectives in Lobster Biology and Fisheries. Information: Dr. Jay Parsons, Aquaculture Unit, Fisheries and Marine Institute, Memorial University, P.O. Box 4920, St. John's, Newfoundland, Canada A1C 5R3 (tel ephone 709 778-0307; fax 709 778-0553; e-mail jparsons@ gill.ifmt.nf.ca).

•**World Aquaculture '99,** 26 April – 2 May 1999, Sydney Convention Centre, Australia. Annual conference and exposition of the World Aquaculture Society. Conference theme: *Bridging the Gap* (emphasis on finding solutions to the gap between world seafood demand and wild capture). Aquafood '99 will be held immediately following the conference at the Sydney Fish Market. Abstracts for oral and poster presentations will be accepted until 31 August 1998. Contact: John Cooksey, Conference Manager, 21910 7th Place West, Bothell, Washington, USA (telephone 425 485-6682, fax 425 483-6319, e-mail worldaqua@ aol.com). Conference home page: http://ag.ansc.purdue.edu/aquanic/was/was.htm.

•**12th International Pectinid Workshop,** Bergen, Norway, 5 – 12 May 1999. Abstract deadline: 1 November 1998. The scientific program includes thematic sessions preceded by invited keynote speakers, special area working groups, and plenary discussions. The number of oral presentations will be restricted and contributors are encourgaed to prepare poster presentations. Interested participants are requested to preregister by contacting Mr. Gunnar Eiken, 12th IPW, Hordaland Fykeskommune, N-5020 Bergen, Norway (fax 47 55 23 93 16, e-mail gunnarek@online.no).

•**Aquaculture Canada '99,** Annual meeting of the Aquaculture Association of Canada, 27 – 29 October 1999,Victoria Convention Center and Empress Hotel, Victoria, British Columbia. Contact: Linda Townsend, (fax 250 755-8749, e-mail townsdl@ mala.bc.ca).

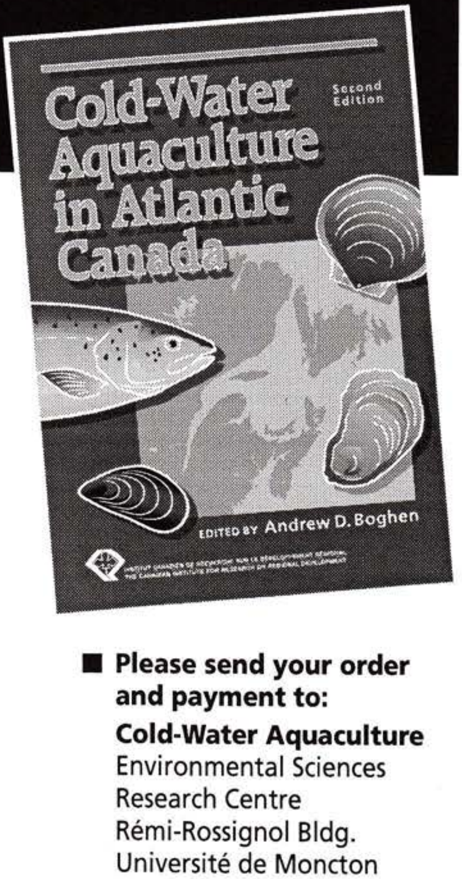
•**AQUA 2000,** 2–6 May 2000, Nice, France. Annual meetings of the World Aquaculture Society and the European Aquaculture Society. Information: John Cooksey, Conference Manager, 21910 7th Place West, Bothell, Washington, USA (telephone 425 485-6682, fax 425 483-6319, e-mail worldaqua@ aol.com).

•**Aquaculture Canada 2000.** Annual meeting of the Aquaculture Association of Canada, June 1-3, Moncton, NB. Information: Dr. Andrew Boghen (tel 506 858-4321, fax 506 855-0177, e-mail boghena@umoncton.ca).

Cold-Water Aquaculture in Atlantic Canada

2nd EDITION

2nd Printing



Revised and substantially updated, **Cold-Water Aquaculture in Atlantic Canada** has been prepared by a team of acclaimed experts. Comprising 17 chapters (672 pages), this book represents a comprehensive overview of all aspects of the aquaculture industry in eastern Canada. It has received excellent reviews and has now become a major reference for producers, administrators and business people. It is being used extensively by colleges and universities offering courses in aquaculture, fisheries and other agri-food related disciplines.

$66.00 (Can.)*

plus postage: $3.00 (Canada)*
$5.00 (U.S.)
$30.00 (overseas)

* Canadian orders please add 7% Tax.

Payment must be in Canadian or U.S. funds.

Payment by cheque:
Make cheque payable to Université de Moncton.

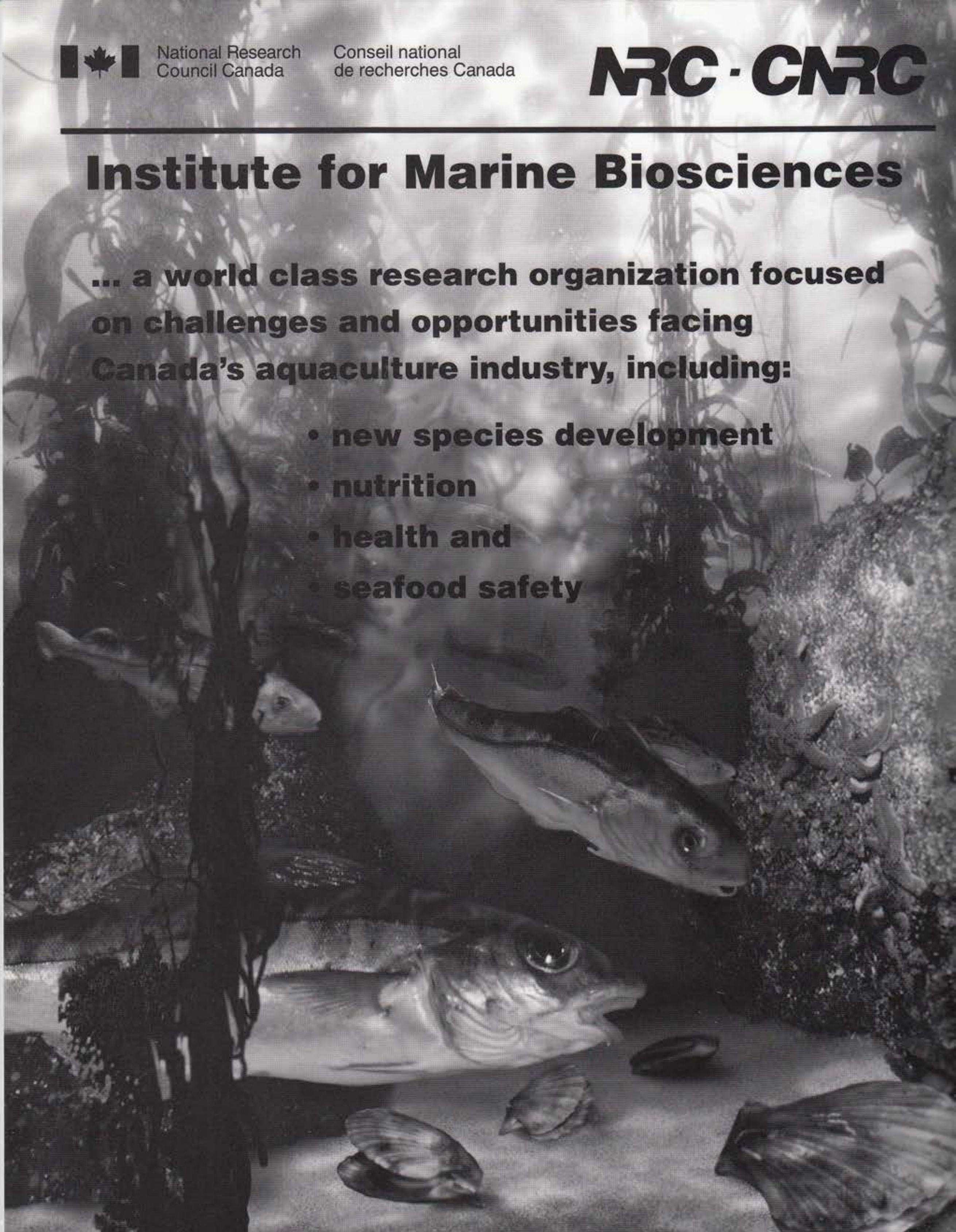
Payment by credit card (Mastercard or Visa):
Please indicate card number, expiry date and name of card holder.

- **Please send your order and payment to:**

Cold-Water Aquaculture
Environmental Sciences
Research Centre
Rémi-Rossignol Bldg.
Université de Moncton
Moncton, New Brunswick
Canada E1A 3E9

Fax: 506-855-0177
E-mail: crse@umoncton.ca

Come browse our web site at:
http://www.sciences.umoncton.ca/ftp_serv/crse/book/



NRC **1411 Oxford Street**
Halifax – NS – B3H 3Z1
http://www.imb.nrc.ca

contact: **Paul Smith**
e-mail: **paul.smith@nrc.ca**
phone: **(902) 426-1186** **fax: (902) 426-9413**