Scientific Excellence • Resource Protection & Conservation • Benefits for Canadians
Excellence scientifique • Protection et conservation des ressources • Bénéfices aux Canadiens

Environmental Requirements of the Sea Scallop (*Placopecten magellanicus*) in Eastern Canada and Its Response to Human Impacts

P.L. Stewart and S.H. Arnold

Biological Sciences Branch
Scotia-Fundy Region
Department of Fisheries and Oceans
Bedford Institute of Oceanography
P.O. Box 1006
Dartmouth, Nova Scotia B2Y 4A2
Canada

1994

Canadian Technical Report of Fisheries and Aquatic Sciences 2005

Fisheries and Oceans / Pêches et Océans

Canada

Canadian Technical Report of Fisheries and Aquatic Sciences

Technical reports contain scientific and technical information that contributes to existing knowledge but which is not normally appropriate for primary literature. Technical reports are directed primarily toward a worldwide audience and have an international distribution. No restriction is placed on subject matter and the series reflects the broad interests and policies of the Department of Fisheries and Oceans, namely, fisheries and aquatic sciences.

Technical reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in *Aquatic Sciences and Fisheries Abstracts* and indexed in the Department's annual index to scientific and technical publications.

Numbers 1–456 in this series were issued as Technical Reports of the Fisheries Research Board of Canada. Numbers 457–714 were issued as Department of the Environment, Fisheries and Marine Service, Research and Development Directorate Technical Reports. Numbers 715–924 were issued as Department of Fisheries and the Environment, Fisheries and Marine Service Technical Reports. The current series name was changed with report number 925.

Technical reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page. Out-of-stock reports will be supplied for a fee by commercial agents.

Rapport technique canadien des sciences halieutiques et aquatiques

Les rapports techniques contiennent des renseignements scientifiques et techniques qui constituent une contribution aux connaissances actuelles, mais qui ne sont pas normalement appropriés pour la publication dans un journal scientifique. Les rapports techniques sont destinés essentiellement à un public international et ils sont distribués à cet échelon. Il n'y a aucune restriction quant au sujet; de fait, la série reflète la vaste gamme des intérêts et des politiques du ministère des Pêches et des Océans, c'est-à-dire les sciences halieutiques et aquatiques.

Les rapports techniques peuvent être cités comme des publications complètes. Le titre exact paraît au-dessus du résumé de chaque rapport. Les rapports techniques sont résumés dans la revue *Résumés des sciences aquatiques et halieutiques*, et ils sont classés dans l'index annual des publications scientifiques et techniques du Ministère.

Les numéros 1 à 456 de cette série ont été publiés à titre de rapports techniques de l'Office des recherches sur les pêcheries du Canada. Les numéros 457 à 714 sont parus à titre de rapports techniques de la Direction générale de la recherche et du développement, Service des pêches et de la mer, ministère de l'Environnement. Les numéros 715 à 924 ont été publiés à titre de rapports techniques du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 925.

Les rapports techniques sont produits à l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre. Les rapports épuisés seront fournis contre rétribution par des agents commerciaux.

Canadian Technical Report of

Fisheries and Aquatic Sciences 2005

1994

ENVIRONMENTAL REQUIREMENTS OF THE SEA SCALLOP (*PLACOPECTEN MAGELLANICUS*) IN EASTERN CANADA AND ITS RESPONSE TO HUMAN IMPACTS

by

P.L. Stewart[1] and S.H. Arnold[1]

Biological Sciences Branch
Scotia-Fundy Region
Department of Fisheries and Oceans
Bedford Institute of Oceanography
P.O. Box 1006
Dartmouth, Nova Scotia B2Y 4A2
Canada

[1]Envirosphere Consultants Limited, Box 2906, Windsor, NS B0N 2T0, Canada

Cat. No. Fs 97-6/2005 ISSN 0706-6457

Correct citation for this publication:

Stewart, P.L., and S.H. Arnold. 1994. Environmental requirements of the sea scallop (*Placopecten magellanicus*) in eastern Canada and its response to human impacts. Can. Tech. Rep. Fish. Aquat. Sci. 2005: ix + 36 p.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

LIST OF FIGURES

ABSTRACT

Stewart, P.L., and S.H. Arnold. 1994. Environmental requirements of the sea scallop (*Placopecten magellanicus*) in eastern Canada and its response to human impacts. Can. Tech. Rep. Fish. Aquat. Sci. 2005: ix + 36 p.

The sea scallop (*Placopecten magellanicus*) is one of the most important commercial invertebrate species in eastern Canada, second only to lobster in landed value. The species occurs widely on offshore banks and in coastal waters from northern Newfoundland to the mid-Atlantic coast of the United States from low tide level to 100 m or more. The most significant populations are concentrated in specific areas having suitable substrate, depth, and food supply and where physical oceanographic features such as current gyres may aid in maintaining populations. Major concentrations occur on Georges Bank, the Scotian Shelf, the Mid-Atlantic Shelf, in the Grand Manan and Digby areas of the Bay of Fundy, in the Baie des Chaleurs, around Iles-de-la-Madeleine, and in Northumberland Strait in the Gulf of St. Lawrence, in Port-au-Port Bay, Newfoundland, and on St. Pierre Bank, in addition to pockets in most coastal areas. The Georges Bank scallop fishery, the largest wild-harvest fishery in the world, is shared by Canada and the United States.

In eastern Canada, sea scallops are exploited principally for their meat (adductor and catch muscles) which commands a high market price. Scallops are harvested commercially by large draggers in offshore areas and smaller vessels and gear in coastal areas, as well as recreationally by SCUBA divers for personal use. The species has potential for aquaculture, particularly where techniques involving suspended culture are employed, and where specialty markets (such as "roe-on-scallop") are targeted. Several commercial aquaculture sites are found in both Nova Scotia and Newfoundland.

The species is not exposed greatly to pollution arising from human development as most of the significant populations are located offshore. Some offshore populations have the potential to be impacted by hydrocarbon development, however, particularly on Georges Bank where major beds coincide with exploitable hydrocarbon reserves. Hydrocarbon impacts include mortality, reduction in growth, metal (barium and chromium) accumulation and tainting after exposure to drilling muds, and tainting and mortality of all life stages resulting from spills and blow-outs. Nearshore scallop stocks in specific locations in eastern Canadian waters have been contaminated by metals from coastal mining and mineral trans-shipping operations. A spill of elemental phosphorus, which resulted in a major die-off of scallops near the source of the spill in Placentia Bay, Newfoundland, in 1969, is the most significant incidence of scallop mortality resulting from industrial contamination. Coastal sewage and fecal contamination is a major factor limiting the availability of locations for scallop culture. Shellfish toxins in coastal waters also limit use of both aquacultured and commercial catches of scallops. Problems experienced in offshore scallop populations off the densely populated middle Atlantic coast of North America (oxygen depletion, offshore sewage contamination with metals and organic compounds and substrate changes) are not presently a problem in eastern Canada.

RÉSUMÉ

Stewart, P.L., and S.H. Arnold. 1994. Environmental requirements of the sea scallop (*Placopecten magellanicus*) in eastern Canada and its response to human impacts. Can. Tech. Rep. Fish. Aquat. Sci. 2005: ix + 36 p.

Le pétoncle géant (*Placopecten magellanicus*) est l'une des espèces commerciales d'invertébrés les plus importantes de l'est du Canada, ne le cédant qu'au homard pour ce qui est de la valeur au débarquement. Il est très répandu sur les bancs du large et dans les eaux côtières, du nord de Terre-Neuve à la côte médio-atlantique des États-Unis, entre la laisse de basse mer et une profondeur de 100 m et plus. Les populations les plus importantes sont concentrées dans des secteurs bien définis qui offrent un substrat, une profondeur et des réserves de nourriture appropriés et où certains phénomènes océanographiques physiques, comme les tourbillons de courants, peuvent contribuer à les maintenir. Les principales concentrations se rencontrent sur le banc Georges, sur la plate-forme Scotian et sur la plate-forme médio-atlantique, dans la baie de Fundy dans les secteurs de Grand Manan et de Digby, dans la baie des Chaleurs, autour des îles de la Madeleine, dans le détroit de Northumberland dans le golfe du Saint-Laurent, dans la baie de Port-au-Port à Terre-Neuve et sur le banc de Saint-Pierre; il y a aussi des gisements isolés dans la plupart des zones côtières. La pêche du pétoncle sur le banc Georges, qui est la plus importante pêche de pétoncle sauvage au monde, est partagée par le Canada et les États-Unis.

Dans l'est du Canada, le pétoncle géant est exploité principalement pour sa chair (muscle adducteur et muscle lisse) qui se vend à prix élevé sur le marché. La pêche commerciale du pétoncle se pratique en haute mer à bord de grands dragueurs et dans les zones côtières au moyen de bateaux et d'engins plus petits; quant à la pêche sportive, elle est pratiquée par des plongeurs en scaphandre autonome pour consommation personnelle. L'espèce se prête à l'aquaculture, surtout là où l'on utilise les techniques de la culture suspendue et où l'on vise des marchés de spécialité (comme celui du pétoncle avec son corail). On compte plusieurs exploitations aquacoles commerciales en Nouvelle-Écosse et à Terre-Neuve.

L'espèce n'est pas fortement exposée à la pollution liée aux activités humaines, car les populations importantes se retrouvent pour la plupart en haute mer. Ces populations peuvent toutefois être touchées par l'exploitation des hydrocarbures, en particulier sur le banc Georges où des gisements importants sont présents dans des sites de réserves d'hydrocarbures exploitables. Parmi les effets des hydrocarbures, citons la mortalité, la réduction de la croissance, l'accumulation de métaux (baryum et chrome) et l'altération du goût ou de l'odeur par suite de l'exposition aux boues de forage, et enfin cette même altération et la mortalité à toutes les étapes du développement par suite d'éruptions et de déversements accidentels. Dans l'est du Canada, certains stocks côtiers de pétoncles ont été contaminés par des métaux en provenance des exploitations minières de la côte et des opérations de transbordement de minéraux. En 1969, un déversement de phosphore élémentaire dans la baie Placentia, à Terre-Neuve, a causé une mortalité massive de pétoncles près de la source de l'accident; c'est le taux de

mortalité le plus élevé qu'ait jamais provoqué une contamination industrielle. La contamination par les eaux usées et les matières fécales le long des côtes est l'un des principaux facteurs qui freinent le développement des installations de culture du pétoncle. Les toxines algales dans les eaux côtières limitent également la pêche commerciale et la culture du pétoncle. Les problèmes que connaissent les populations marines de pétoncles sur la côte médio-atlantique, très peuplée, de l'Amérique du Nord (déplétion de l'oxygène, contamination par les eaux usées contenant notamment des métaux et des composés organiques, altération du substrat) ne se posent actuellement pas dans l'est du Canada.

PREFACE

Habitat managers in the Department of Fisheries and Oceans (DFO) often require key information on the habitat and environmental requirements of resource species in order to assess the potential impacts of industrial and other types of development. Such information is often spread over various diverse sources including reference books, scientific journals, technical reports, unreferenced hard copy, and computer files, as well as in the memory of individuals. It follows that the information is often difficult and time consuming to access. As a result, managers often must make decisions without the benefit of key material because it is not readily available to them. This document is one of a series of technical reports that attempts to rectify this situation by making available user-friendly habitat profiles summarizing existing information on species life history, habitat requirements, and known anthropogenic effects on their populations.

Building on the model of the successful pilot project on lobster[1] conducted by DFO's Marine Atlantic Standing Subcommittee on Habitat (MASSH) in 1992, this report and two other profiles[2,3] have recently been produced. The current project, which involved literature review and consultation, was undertaken under contract by Envirosphere Consultants Limited of Windsor, Nova Scotia. The three species - Atlantic herring, blue mussel, and sea scallop - were selected jointly by the four Atlantic Regions of DFO (Newfoundland, Scotia-Fundy, Gulf, and Québec). Each report is published in English and French as a single document. Funding for this work was provided through the Sustainable Fisheries Program of Environment Canada's Green Plan.

We hope that it will be possible to develop further profiles in the near future, and welcome your suggestions and ideas for improving the usefulness of these profiles.

Donald C. Gordon
Project Manager
Biological Sciences Branch
Department of Fisheries and Oceans
Scotia-Fundy Region

H. Brian Nicholls
Scientific Authority
Marine Assessment and Liaison Division
Department of Fisheries and Oceans
Scotia-Fundy Region

---

[1]Harding, G.C. 1992. American lobster (*Homarus americanus* Milne Edwards): A discussion paper on their environmental requirements and the known anthropogenic effects on their populations. Can. Tech. Rep. Fish. Aquat. Sci. 1887: vi + 16 p.

[2]Stewart, P.L. 1994. Environmental requirements of the blue mussel (*Mytilus edulis*) in eastern Canada and its response to human impacts. Can. Tech. Rep. Fish. Aquat. Sci. 2004: x + 41 p.

[3]Stewart, P.L., and S.H. Arnold. 1994. Environmental requirements of the Atlantic herring (*Clupea harengus harengus*) in eastern Canada and its response to human impacts. Can. Tech. Rep. Fish. Aquat. Sci. 2003: ix + 37 p.

NATURAL HISTORY

GENERAL FEATURES

Sea, or giant, scallops (*Placopecten magellanicus* [Gmelin 1791]) are molluscs, having two saucer-like shells (valves) roughly equal in diameter, held together by a hinge composed of flexible protein. One valve is flat, smooth, and off-white, and is the one on which the scallop normally rests, while the upper valve is rounded, having concentric bands of alternating colours (frequently reddish) in adult animals. Flarings of the shell at the hinge are known as wings or ears. The internal organs and tissues, which can make up 40% of the wet weight, are dominated by two gills, the "meat" (adductor and catch muscles), and the gonad. Only the meat is the product normally consumed in North America.

P. magellanicus is a filter feeder which uses the gills to concentrate phytoplankton and other suspended particulate material from the water. The shell can be opened to admit water for filtering, and closed to avoid harmful stimuli, although unlike many mollusc species the shell cannot be tightly closed. A layer of tissue (the mantle) lines the inside surface of the shell and is responsible for secreting it. The thickened muscular part of the mantle along the perimeter of the shell ("the rim") is equipped with iridescent, light-sensitive eyes and sensory tentacles. The round adductor and "catch" muscles are located centrally and join the two valves of the shell.

An ability to open and close the valves rapidly ("clapping") using its powerful adductor muscle enables the sea scallop to expel water from the corners of the hinge and propel itself over limited distances to avoid unfavourable conditions and predators. Scallops can move 4 to 5 m horizontally and 1 m or more off the bottom by clapping. If left undisturbed, scallops swim infrequently; but swimming combined with local currents can aid in dispersal of the species (Manuel and Dadswell 1991; Hatcher et al. in press). Young scallops swim most frequently, and individuals become less likely to swim as they age. Swimming is rarely seen in scallops larger than 110 mm shell height.

GEOGRAPHIC AND DEPTH DISTRIBUTION

P. magellanicus occurs on the Atlantic continental shelf of North America from the north shore of the Gulf of St. Lawrence to Cape Hatteras, North Carolina. The species typically occurs in relatively shallow water, from just below tide level to depths of 100 m or more. In the Gulf of St. Lawrence (Baie des Chaleurs, Northumberland Strait, Magdalen Shallows, and west coast of Newfoundland) sea scallops are mainly found at depths of 10 to 25 m (Davidson, DFO, pers. comm.). Sea scallops rarely occur deeper than about 110 m, but some deep-water populations occur (e.g. 170 to 180 m in the Gulf of Maine) (Barber et al. 1988). Scallops in the northern parts of the range do not occur as deep as in more southerly populations (Naidu 1975) in response to their requirement for warmer temperatures afforded by surface waters.

SCALLOP BEDS

Sea scallops often occur in dense aggregations called beds, which frequently support commercial fisheries (Fig. 1). Beds may be sporadic (lasting on the order of up to a few years) or essentially permanent (e.g. commercial beds supporting the fishery on Georges Bank). The highest concentration of many permanent beds appears to correspond to areas of suitable temperature, food availability, and substrate (typically coarse, clean bottom such as gravel) where physical oceanographic features such as fronts, and gyres (large-scale circular current patterns), may keep larval stages in the vicinity of the spawning population (Thouzeau et al. 1991a; Tremblay and Sinclair 1992).

LIFE CYCLE

The life cycle of *P. magellanicus* involves a planktonic stage (drifting in the water column) which develops into a form which settles to the seabed (Fig. 2). Eggs develop in 1 to 2 d at 13 to 15°C into the first of three larval stages which together last about 5 wk (Culliney 1974; Black et al. 1993). The larval scallops drift in the water but can swim freely, and appear to follow a daily vertical migration of up to several metres, occupying shallower depths at night (Tremblay and Sinclair 1988; 1990). During the planktonic stage, a shell, an eye spot, and a foot develop (Naidu 1991). Duration of stages is shorter at higher temperatures and where food is more plentiful.

Scallop larvae settle to the seabed at a size of about 0.25 mm and develop the remaining features to enable them to live there (metamorphosis). Under unsuitable bottom conditions, settlement may be delayed; and larvae can remain in the plankton for up to 1 mo (Culliney 1974). Newly settled larvae (spat) attach to a suitable substrate on the seabed by secreting threads (byssus) (Culliney 1974). Spat attach predominantly on the exposed undersides of gravel and shell fragments - a behavioral pattern which may provide them with protection from predation (Culliney 1974).

As young sea scallops age, they become less mobile and show less tendency to attach to the bottom using byssus threads (Caddy 1972; MacKenzie 1979). The survival rate of newly settled spat is low, with the number entering the adult population fluctuating greatly from year to year, depending on dietary conditions, predation, damage caused by shell-boring organisms, parasitism and disease, and by occurrence of lethal water temperature.

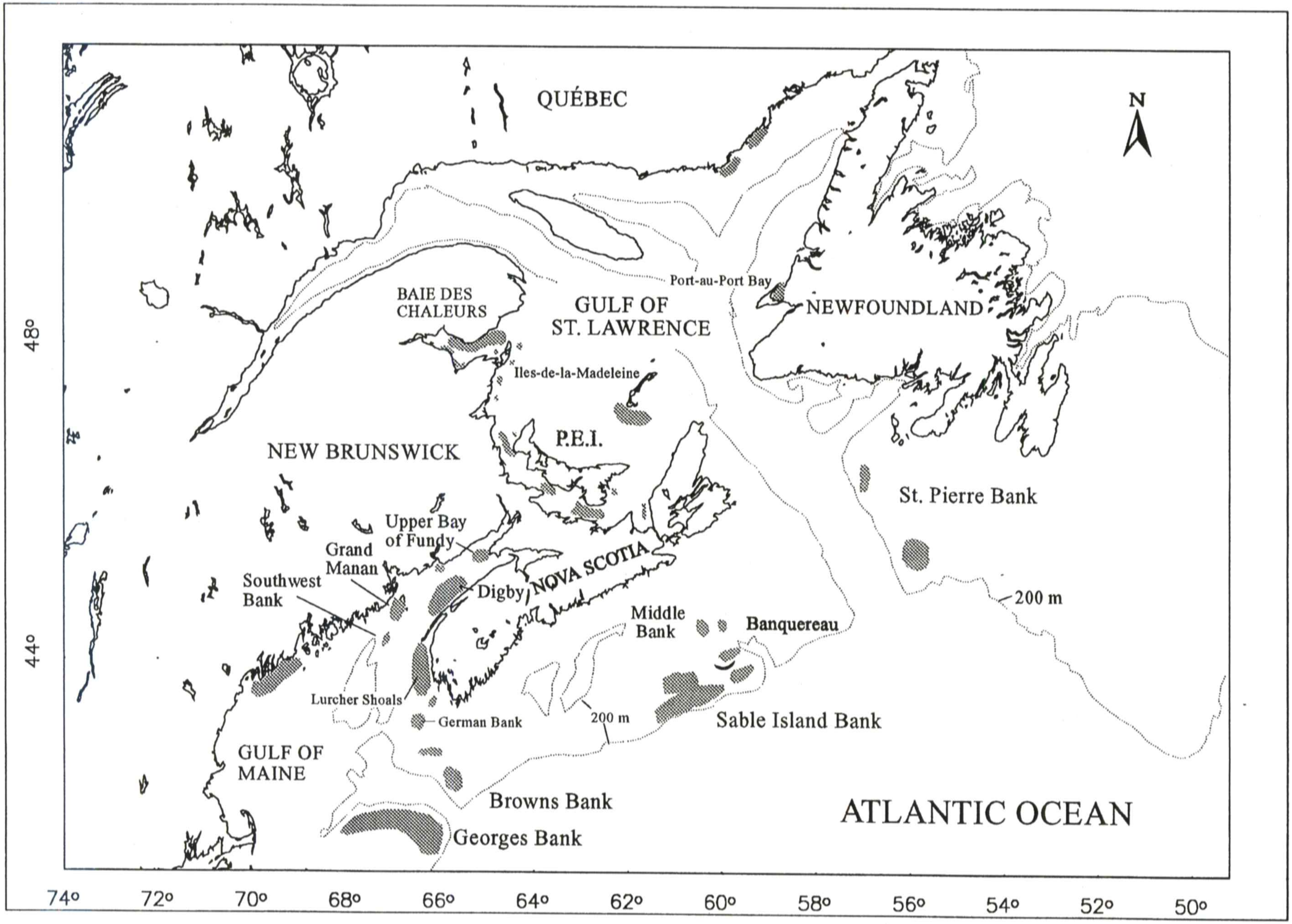

Figure 1. Major areas of fishing activity for the sea scallop *Placopecten magellanicus* in eastern Canada.

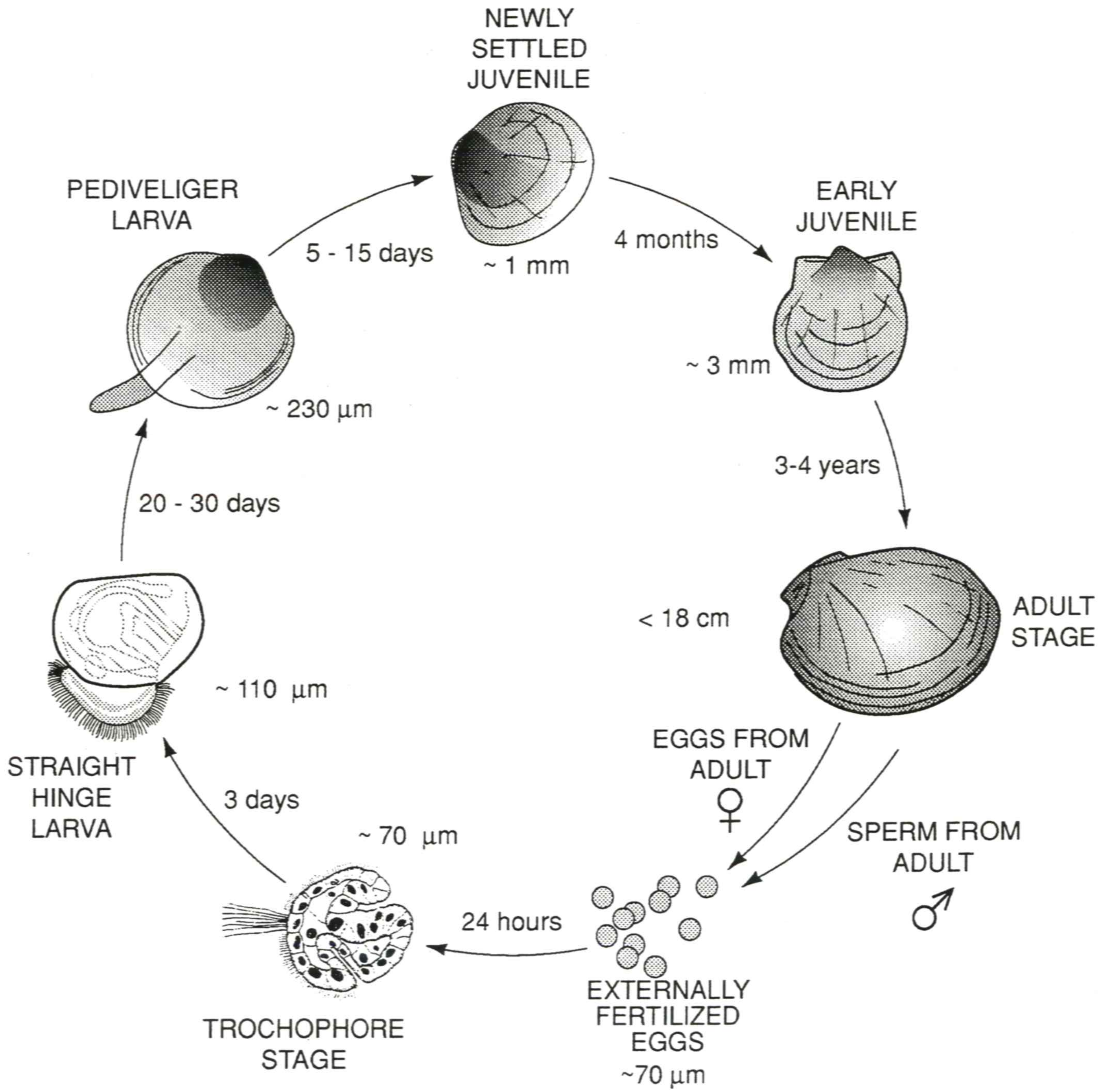

Figure 2. Life cycle of the sea scallop *Placopecten magellanicus*.

SEASONAL CYCLES

Reproduction

The life cycle of *P. magellanicus* is usually centred on a major annual spawning period in the late summer to fall (August to October), when scallops release eggs and sperm into the water column (Parsons et al. 1992). Spring or early summer (June-July) spawning also occurs at specific locations, and both spring and fall spawning occur in some areas (west coast of Newfoundland, Georges Bank, mid-Atlantic coast of the United States) (Davidson et al. 1993). The major spawning times in eastern Canada include: July (Gulf of St. Lawrence, Québec lower north shore), late July to early September (Northumberland Strait), late August to early September (Bay of Fundy), July to September (Passamaquoddy Bay, New Brunswick), April-May and late September (Georges Bank), mid August to mid September (Baie des Chaleurs), and early September (Iles-de-la-Madeleine) (Davidson et al. 1993; Dibacco 1993; Giguère et al. 1994; Giguère, DFO, pers. comm.; Parsons et al. 1992).

Scallops in particular beds generally spawn synchronously in a short time, but "dribble spawning" (periodic pulsed spawning) has been reported in scallops from Newfoundland coastal waters (Naidu 1970). A rapid temperature change, the presence in the water of sperm from other scallops, agitation, or tides may trigger scallop spawning (Parsons et al. 1992).

In general, sea scallops in eastern Canada are capable of spawning by their third year (L.A. Davidson, DFO, pers. comm.). Adult scallops channel a significant part of their energy into developing eggs or sperm; consequently, development of reproductive organs is closely tied to the availability of food and accumulated energy reserves. The amount of energy channelled into reproduction increases as the animal ages. Upon reaching maximum shell height, all excess energy goes into reproduction. Scallops limited by food (as can occur in deep-water populations) generally produce fewer eggs, and some populations in areas having low food availability do not spawn (Thompson and MacDonald 1990).

Growth

P. magellanicus grows in response to a positive balance between the food energy obtained and the energy required for reproduction, tissue and shell growth, and for performing basic functions including feeding and swimming. A wide range of growth rates occurs in eastern Canadian scallop populations. Some of the highest growth rates have been observed on Georges Bank and in Port-au-Port Bay on the west coast of Newfoundland where scallops reach a harvestable size of about 100 mm at an average age of 4 to 5 yr (Black et al. 1993). Other populations may take 5 to 7 yr or more to reach the same size. Scallops from the Gulf of St. Lawrence generally have slower growth rates than Gulf of Maine and Bay of Fundy scallops (Chouinard and Mladenov

1991). Scallops can reach 20 yr of age in areas which are not heavily exploited by the commercial fishery, and may attain shell heights of 21 cm.

Local variations in growth rate depend on a number of environmental factors, but food availability and temperature are most important. In general, growth of *P. magellanicus* is slower in winter, in deep water, and on bottoms having fine sediments.

FEEDING

P. magellanicus is a suspension or filter feeder, using currents created by short hairs (cilia) on the gills to move and filter water containing suspended particulate material. Elevated concentrations of inorganic suspended material and clay-sized particles can interfere with scallop feeding, but the presence of low concentrations (<0.5 mg/L) of inorganic particulate matter in the diet may be important in enabling sea scallops to utilize phytoplankton cells efficiently (Cranford and Gordon 1992).

Suspended material from water drawn into the shell is captured selectively on the gills and is transferred along the gill to the mouth area. The exact mechanism of filtration is not known, but it includes a combination of sieving and other factors (Beninger 1991). Once captured, the particles are mixed with mucus and channelled in strings to the oral groove, located at the base of the gills. The mixture is passed to a pair of tissue flaps (labial palps) which can reject some of the mucus and non-nutritious particles bound in it. The rejected material (pseudofaeces) is expelled with the outgoing water current. At very high particle concentrations, most material is rejected. A row of tentacles on the innermost margin of the mantle fold (velum) may perform a screening function to limit entry of relatively large particles into the mantle cavity.

Scallops can filter significant quantities of water, from 2 to 20 L/h depending on temperature and food content (Cranford and Gordon 1992; Cranford, DFO, pers. comm.). Feeding rate and patterns are influenced by many factors such as temperature, salinity, particle concentration, and size. The presence of phytoplankton or cell components and metabolites, even at low concentrations, can cause an increase in filtering and ingestion rate in *P. magellanicus* (Ward et al. 1992). Currents above about 10 cm/s can reduce feeding rate (Wildish and Saulnier 1992). Strong tidal currents inhibit feeding, but the scallop gets adequate energy from efficiently filtering during slack water (Wildish and Kristmanson 1988). In a regime of currents above 10 cm/s, *P. magellanicus* grows at different rates depending on its orientation on the bottom. Scallops gaping into currents stronger than 10 cm/s showed lower growth than those having the hinge facing into the current (Fréchette 1989). No difference in growth was observed in either orientation if currents were below 10 cm/s. The adult sea scallops' tendency to rest in seabed depressions may enable it to improve its feeding ability by taking advantage of reduced currents in the sediment boundary layer (Brand 1991).

PARASITES AND DISEASES

No serious parasites or diseases of sea scallops are known from eastern Canada, but serious incidents of mortality of undetermined origin do occasionally occur (e.g. an unexplained die-off in the inshore scallop zone occurred off Digby, Nova Scotia, in 1988-89). Parasitic flatworms use the species as a host during parts of their life cycle, and their presence can lead to pearl formation (bumps in the shell or loose "pearls" where the parasite is encased with shell material). "Brown-spot," a bacterial disease causing 1 to 4 mm brown spots in white meats, occurs in some scallops (usually larger ones) and leads to the rejection of meats as unmarketable. Some harmless ciliate parasites may also occur. Scallops are frequently colonized by boring worms *Polydora* spp. and encrusting sponges (e.g. *Cliona* spp.). Uncommonly, extreme development of these species (as may occur in old scallops) may perforate and weaken the shell, stressing the scallop and leading to the development of an unmarketable adductor muscle (Getchell 1991; McGladdery et al. 1993; McGladdery, DFO, pers. comm.). Presence of *Chlorella* sp. (an algal species) can occasionally turn the tissues of sea scallops bright green.

ASSOCIATIONS WITH OTHER SPECIES

P. magellanicus is a member of a seabed community of organisms having similar environmental requirements (Thouzeau et al. 1991b; MacKenzie 1979). The sea-snail (*Liparis inquilinus*) and juvenile red hake (*Urophycis chuss*) live inside the shells of some sea scallops, apparently without harm to the host. Hake up to 11.6 cm have been found in scallops. Prolonged scallop dredging activity can alter the community composition of scallop beds (Langton and Robinson 1990).

PREDATORS

P. magellanicus is subjected to predation at all life stages. Planktonic larvae are exposed to predation by larger zooplankton, as well as to larval and adult planktivorous fish. After settlement, the juvenile scallops fall prey to invertebrates such as starfish, predatory snails, crustaceans (crabs and lobster), and to various bottom fish species (commonly winter flounder, cod, wolffish, and American plaice) (Jamieson et al. 1982; MacKenzie 1979; Naidu and Meron 1986).

ENVIRONMENTAL REQUIREMENTS

TEMPERATURE

P. magellanicus is a cold water species and grows optimally at temperatures of 10 to 15°C (Young-Lai and Aiken 1986). Temperatures of 21 to 24°C are lethal to adult scallops depending on acclimation temperature (Dickie 1958; Gould and Fowler 1991).

Cold temperatures limit the northern distribution of the species, and spawning and larval development are prevented or delayed by exceptionally low summer temperatures (MacKenzie 1979). The upper temperature limit determines the southern inshore distribution along the Mid-Atlantic Shelf. Scallops in coastal areas can die if they are subjected to shifts in the thermocline, and sudden changes in temperature can debilitate them and hamper escape from predators (Dickie and Medcof 1963).

SALINITY

Generally, sea scallops can tolerate reduced salinities; but optimal survival is obtained at levels approaching full-strength seawater (Young-Lai and Aiken 1986). The lethal threshold for adults is 16.5‰, although scallop larvae in the laboratory can remain viable for 42 h or more at 15°C in a salinity of 10.5‰ (Culliney 1974; MacKenzie 1979).

DISSOLVED OXYGEN

Scallops are sensitive to reduced oxygen level, but populations are rarely exposed to such conditions in nature. In inshore waters, decreased oxygen can result from discharges of organic matter from pulp and paper mills, fish-processing plants, and domestic sewage outfalls. Oxygen reductions in bottom water over 8600 km^2 off New Jersey due to offshore waste disposal and nutrient and organic inputs from the Hudson River, New York, caused significant scallop mortalities (10% of stocks) as well as resulting in declines in other species (Gould and Fowler 1991).

SUSPENDED PARTICULATE MATTER

P. magellanicus feeds on the organic component of suspended particulate matter (SPM) but is sensitive to inorganic suspended particulate material, particularly to fine (clay-sized) particles. Concentrations of clays as low as 10 mg/L can impact energy balance and survival of sea scallops (Cranford and Gordon 1992). Scallops usually are most abundant in areas having relatively low SPM concentrations. Suspended particulate levels on scallop grounds on Georges Bank are from 0.1 to 2.0 mg/L (Bothner et al. 1981); coastal Newfoundland waters may have SPM concentrations of 1 to 6 mg/L (Thompson 1984).

Sea scallops have a limited capacity to reject non-living inorganic particles. Clay-size particles are not effectively rejected by scallops, causing a "dilution" effect on the nutritional value of ingested particles. Clay can be particularly harmful, apparently clogging cilia, and may cause reduced filtration and in some cases death (Cranford and Gordon 1992). Areas where scallops occur usually have coarse substrate such as gravel, cobble, and rock having a minimal content of fine particles. An area known as the "Mud Patch" (south of Block Island, off southern New England) is known to have a high proportion of stressed scallops, possibly because of the fine sediment on the bottom and in suspension (Gould and Fowler 1991).

In shallow coastal waters, storms can resuspend bottom sediments, elevating levels of suspended particulate matter over normal levels by one order of magnitude or more (Bohlen et al. 1979). The presence of inorganic particulate matter at high concentrations is stressful for scallops, as the species must filter larger water volumes to extract an adequate amount of food; but such episodes are generally short lived. In the laboratory, suspended sediment at low concentrations appears to enhance growth over pure algal diets.

FOOD

P. magellanicus is exposed to a range of food material contained in the suspended particulate matter it filters from the water. The principal food is phytoplankton, but detrital particles (pieces of dead organic material) and associated bacteria can also contribute to energy gain during periods of low phytoplankton concentrations (Grant and Cranford 1991). Detritus is less nutritious for scallops than phytoplankton, however, owing to the relative lack of nitrogen in detritus (Cranford and Grant 1990) and to the small fraction of organic material that may be used by scallops. Dissolved organic material (absorbed through the tissues) has been suggested to be an additional minor nutrition source, particularly in scallop larvae (Marshall and Lee 1991).

Components of the diet vary in abundance depending on the geographic location of the bed. Sea scallops in coastal areas and bays encounter more seaweed and seagrass detritus and may be exposed periodically to significant amounts of resuspended inorganic material. Offshore scallops feed mainly on phytoplankton and resuspended organic material. Phytoplankton appear to be necessary for meeting scallop energy demands, although seaweed detritus may be an important food supplement in nearshore environments (Grant and Cranford 1991). Areas of adequate water exchange are most suitable for scallops by providing greater access to food and oxygen.

SUBSTRATE

Sea scallops are generally found in seabed areas having coarse substrate, typically gravel, shells, and rock, which permit attachment of juveniles and are associated with generally low inorganic suspended matter concentrations in the water (which favour scallop feeding). *P. magellanicus* is significantly more abundant on gravel than on any other sediment type (Thouzeau et al. 1991a). Many of the offshore banks in eastern Canadian waters have gravel and cobble bottoms which are favourable for scallop colonization.

WAVES, CURRENTS, AND GYRES

Water movement is important for scallops through the replenishment of suspended food material, supply of oxygen, and removal of waste products. Water movements also help to disperse larvae and adults.

Although suspension feeders generally benefit from a food supply brought by currents, too much current (generally above about 10 cm/s) inhibits sea scallop feeding. *P. magellanicus* can grow and reproduce in areas such as the Bay of Fundy which have significant tidal currents, because periods of slack water are long enough to allow the scallops to feed (Wildish and Kristmanson 1988; MacDonald and Bajdik 1992; Wildish and Saulnier 1992). In some cases, sea scallops have been shown to have a preferred upstream orientation of the water intake for feeding (inhalant aperture) and a downstream orientation of the outgoing flow (MacDonald and Bajdik 1992), although in high currents they grow better with their open margin facing downstream (Fréchette 1989).

Persistent physical oceanographic features such as gyres and fronts may retain larvae in areas where the parent stock is found, thus enabling *P. magellanicus* larvae to settle in areas where conditions are conducive to maintaining the beds. Tidal currents on offshore banks frequently lead to "net" or "residual" circular current patterns (gyres). A particularly well-developed gyre, strong tidal fronts, and vertical mixing on Georges Bank are believed to have contributed to the major scallop stock there (Tremblay and Sinclair 1992). A gyre in the outer part of the Bay of Fundy is also thought to retain some scallop larvae while others are transported to the inner Bay (Tremblay and Sinclair 1988). Scallops spawned in inshore bays may be retained by local circulation patterns.

ECONOMIC IMPORTANCE AND RESOURCE USE

Sea scallops have supported valuable fisheries in eastern Canada for more than 100 yr (Naidu 1991) and were used even by early native populations prior to European colonization (Bourne 1964). Today, the sea scallop fishery is one of the most lucrative in eastern Canada; and *P. magellanicus* is the most important commercially exploited molluscan shellfish species in Canada.

COMMERCIAL AND RECREATIONAL FISHERIES

The sea scallop fishery is the second most valuable commercial invertebrate fishery species in Canada (following American lobster). In 1992 the combined landed value of scallops in eastern Canada was $100.6 million, of which the sea scallop made up the vast majority. Major commercial scallop fisheries occur on Georges Bank, in the Bay of Fundy (particularly off Digby, Nova Scotia), on the Scotian Shelf, in the Gulf of St. Lawrence (Northumberland Strait, Baie des Chaleurs, around Iles-de-la-Madeleine, along the Québec north shore, and in Port-au-Port Bay, Newfoundland), and on St. Pierre Bank. Sea scallops are widely distributed in Newfoundland coastal waters, and pockets occur in coastal areas throughout eastern Canada. Toward the extremes of their range, scallops have generally been less successful at sustaining exploitation (Naidu and Anderson 1984).

Sea scallops are harvested predominantly for the meat, but markets for roe and whole scallop in Europe and Japan have drawn industry attention. Markets for scallop gonads (roe) require that the meat be attached (roe-on-scallop). In Canadian waters the presence of shellfish toxins in tissues other than the meat limits the sale of whole scallops.

Offshore scallops are fished with relatively large vessels (20 m to 46 m) towing heavy dredging equipment. Inshore draggers are typically under 20 m (Naidu 1991). The gear, called drags, rakes, or dredges, consists of a heavy iron frame and bag(s) made from steel ring mesh. Offshore drags are typically larger (4 to 4.6 m in width), while inshore gear may be 2.5 m wide. Inshore drags are typically towed in tandem arrays of up to four or five buckets (so-called "Digby-type" drags) (Black et al. 1993; Naidu 1991; Roddick and Miller 1992).

Before 1945, the Canadian scallop fishery was an inshore operation centred in the Bay of Fundy off Digby and in Mahone Bay, Nova Scotia. Stocks in Port-au-Port Bay, Newfoundland, and on St. Pierre Bank were developed after the Second World War into major commercial fisheries which collapsed through overfishing in the late 1950s (Naidu 1991; Templeman 1966). Offshore scallop draggers which had pursued these fisheries subsequently moved to the more productive Georges Bank stocks.

Approximately 75% of Canadian scallop landings come from Georges Bank, which has been continuously exploited since the 1950s by Canadian and American fleets. Three strong year classes have produced major peaks in landings in the last 30 yr, and catches have increased regularly since 1988 (CAFSAC 1992).

Sea scallop fisheries are currently controlled by regulations which limit landings of undersized scallops. Meat count regulations (limiting number of scallop meats per unit weight) have been in place since 1973 in the offshore fishery. Recreational scallop harvesting is permitted by SCUBA divers in New Brunswick and Nova Scotia under license, but is not permitted in Newfoundland and Québec waters. Some scallops are also taken recreationally in eastern Canada by rakes, tongs, and dip nets (Naidu 1991).

AQUACULTURE

Background

Techniques for scallop culture (based mainly on Japanese culture methods) have been developed for eastern Canadian waters, and the potential for successful operations has been identified in many locations. The most promising areas are along the Atlantic coast of Nova Scotia, in coastal areas of Newfoundland, where several commercial operations have recently begun, and in the Iles-de-la-Madeleine where experimental operations are under way.

Sea scallops have the advantage of having a high market price, both for meats and for whole animals destined for specialty markets. Nonetheless, slow growth in the final "grow-out" stage of cultured scallops, combined with high equipment and labour costs, have in the past contributed to a marginal economic outlook for scallop cultivation. Use of "ear hanging" and other suspension culture techniques as a means of carrying out the final growth phase, instead of bottom culture, offers a more rapid growth and if adopted widely appears likely to make the industry viable (Dadswell and Parsons 1991).

Aquaculture Techniques

Aquaculture sites are generally located in areas having natural populations of scallops to provide a source of newly settled larvae (spat), although hatchery-reared spat are used in some cases. The presence of existing beds also indicates favourable conditions such as food supply, water movement, depth, and adequate temperature to promote high growth rates. Operators use well-established techniques to collect spat and maintain them as they grow over 3 to 5 yr to market size. Collectors used typically in eastern Canada consist of porous woven plastic bags (onion bags) filled with monofilament gillnet, which are suspended 2 to 6 m off the bottom from moorings at the culture site (Naidu and Cahill 1986) (Fig. 3). The scallop larvae enter the bags and attach to the monofilament line, on which they are allowed to grow for 9 to 12 mo, reaching a size of 8 to 14 mm (Dadswell and Parsons 1991; Young-Lai and Aiken 1986). The onion bags also retain young scallops dislodged from the net during handling.

Scallop juveniles from the collectors are placed in suspended strings of pyramidal net cages (pearl nets) for about 1 yr, during which they may be thinned and redistributed to other nets (Fig. 3). At 40 to 60 mm, the juvenile scallops may be either transferred to accordion-like multi-tiered nets (lantern nets), individually suspended from longlines (commonly by means of fasteners inserted through holes drilled in the ear of the shell [ear hanging] or other individual attachment methods) or transferred to the seabed at the site for final grow-out (benthic relaying). Ear-hung scallops require no further transfer until commercial harvest.

In comparison with ear hanging and suspended net culture, benthic relaying requires a large area of sea bottom and takes nearly twice as long to achieve marketable scallops. Growth to commercial size in suspended culture may take 3 to 5 yr (Dadswell and Parsons 1991; Wildish et al. 1988). Predation on cultured scallops by starfish and other invertebrates can be a problem for aquaculture operations. Procedures at a site usually involve cleaning, during which predators are removed (Wildish et al. 1988).

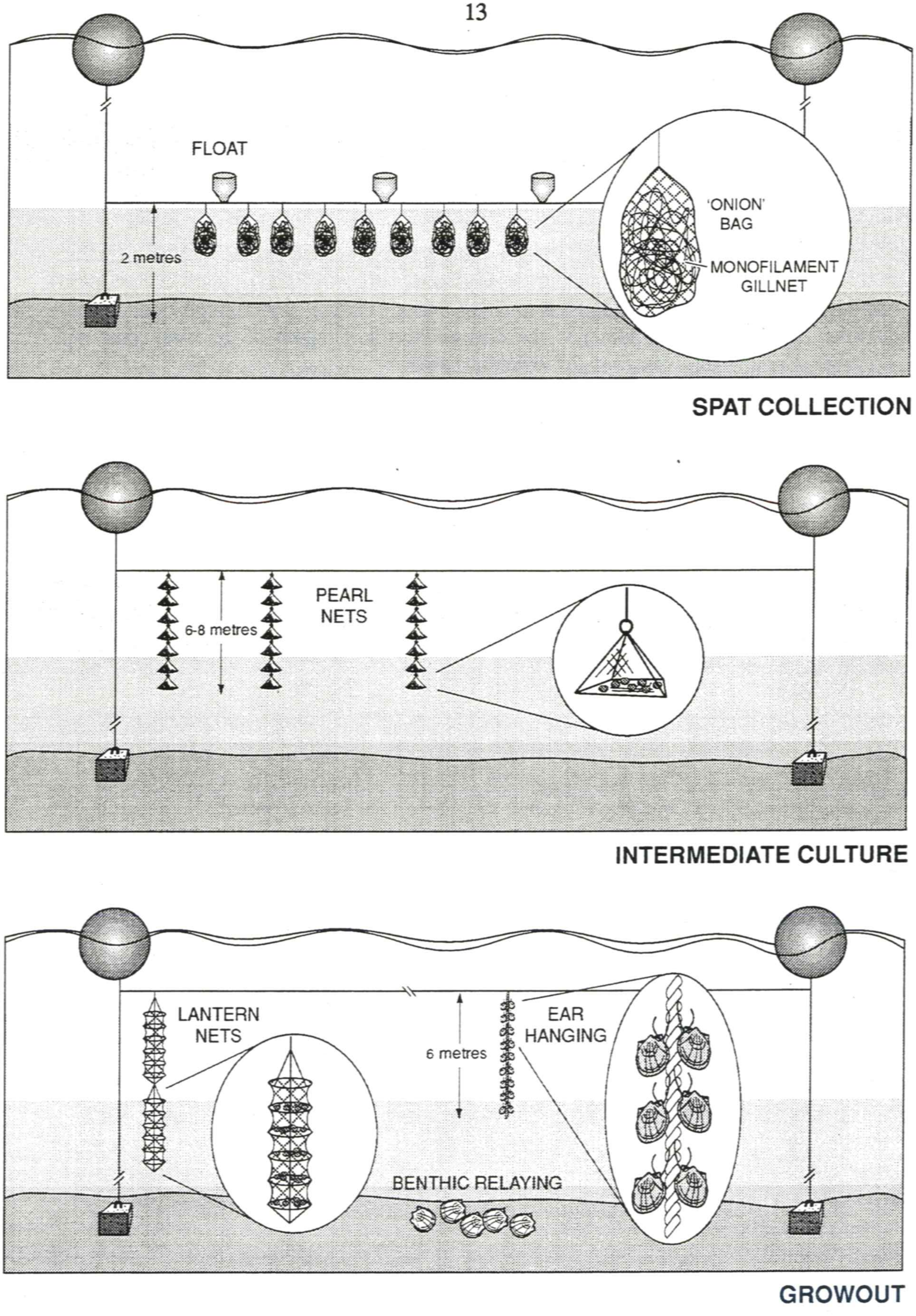

Figure 3. Generalized sea scallop aquaculture techniques in eastern Canada.

Distribution

Scallops have been cultured successfully in various areas of coastal Newfoundland, in Mahone Bay, Lunenburg Harbour, and the eastern shore, Nova Scotia, in the Passamaquoddy Bay area of New Brunswick, and in the lagoons of Iles-de-la-Madeleine. Experimental scallop culture in other areas, such as the Baie des Chaleurs and the St. Lawrence north shore, have not been successful (Carter and Béland 1984), although there still may be potential in these areas. Present commercial operations in Newfoundland occur principally in the Port-au-Port Bay region of the west coast and in Nova Scotia at several sites on the Atlantic Coast.

Environmental Impacts

Due to the relative newness of scallop aquaculture in eastern Canada, environmental impacts of operations have yet to be determined. Impacts of suspended scallop aquaculture may be similar to those encountered in mussel farms, namely an increased load of organic matter and elevated nutrient release from the seabed (Grant et al. in press). Scallop culture operations using seabed grow-out are not likely to have the same impact as operations using suspended culture, where higher stocking densities of scallops can occur.

Scallop spat have been shown to be able to retain cells of toxic phytoplankton in the gut for short periods; and transfer of spat from areas having toxic algal species (see "Shellfish Toxins" section below) has the potential to contaminate "clean" areas (Scarratt et al. 1993), although no such incidents have been reported.

SHELLFISH TOXINS

Sea scallops can accumulate toxins of paralytic shellfish poisoning (PSP); but the toxin tends to concentrate in the viscera, not in the meat, and so PSP in scallops is not generally a significant health hazard in eastern Canada (Jamieson and Chandler 1983). Incidents of PSP poisoning involving scallops are less common than those involving mussels and soft-shell clams and account for $<1\%$ of reported cases and no deaths (Prakash et al. 1971). Advent of a roe-on-scallop fishery and increased interest in markets for whole scallop, particularly through aquaculture operations, have led to tighter Canadian monitoring of PSP in scallops, even in offshore areas. The roe-on-scallop fishery on Georges Bank has at times been closed when viscera concentrations of PSP toxin (saxatoxin) exceeded safe levels, while concentrations in the meat were not detectable (Gillis et al. 1991).

The main toxic species involved in paralytic shellfish poisoning are the dinoflagellates *Alexandrium fundyense* (Bay of Fundy and Newfoundland) and *A. excavatum* (Gulf of St. Lawrence). Sea scallops can have elevated and dangerous levels of PSP toxin in tissues other than the meats year-round, as they can also ingest and accumulate PSP from the overwintering cysts of *Alexandrium* stirred up from bottom sediment (Jamieson and Chandler 1983). Unsafe tissue levels of the PSP toxin have been observed periodically in scallops, even in offshore areas such as Georges Bank (Martin et al. 1992; Gillis et al. 1991). Concentrations of PSP toxin have also been found in stomachs and other tissues of scallops along the northeastern coast of Newfoundland (Hawryluk et al. 1992). In the late 1970s to early 1980s only the Bay of Fundy was considered to have toxic levels of PSP through most of the year (Jamieson and Chandler 1983). *P. magellanicus* is highly resistant to the effects of the toxin and may have mechanisms for inactivating it. Toxins accumulated by scallops can be passed up the food chain to other species such as lobster (Haya et al. 1992).

P. magellanicus has not been implicated in poisoning events involving amnesic shellfish poisoning (ASP) or diarrhetic shellfish poisoning (DSP).

HUMAN IMPACTS

ENVIRONMENTAL CONTAMINANTS

A wide range of environmental contaminants may occur in the marine environment. Scallops, as suspension feeders, are exposed to large volumes of water and suspended particulate material from which they can absorb and concentrate contaminants. Most commercial scallop populations occur in offshore areas, however, and thus are not usually exposed to elevated concentrations of man-made contaminants, although offshore populations may be impacted by pollution from marine transportation, offshore petroleum exploration activity, and in some areas by offshore sewage and waste disposal. Natural scallop beds as well as potential aquaculture sites in coastal areas, however, can be impacted by coastal industrial activity (e.g. Baie des Chaleurs metal mining and shipping) and as well are coming under increasing pressure from development, particularly in the form of sewage and other wastes from coastal settlement.

Responses to Contaminants

P. magellanicus responds physiologically to major classes of environmental contaminants using mechanisms similar to those of other marine bivalves, such as the blue mussel *Mytilus edulis* (Bayne et al. 1985; Viarengo and Canesi 1991). Environmental contamination effects on *M. edulis* have been described in a companion technical report (Stewart 1994).

Sea scallops have adaptive biochemical responses to reduce the effects of various contaminants. For example, in response to the presence of metals (e.g. cadmium), *P. magellanicus* produces proteins having high molecular weight which compare in function to the "heat shock" proteins that are normally produced under heat stress in various organisms (Fowler and Gould 1988; Fowler et al. 1985). Heat shock proteins typically bind and detoxify metals. Sea scallops also respond to exposure to metals by producing low-molecular-weight proteins (Gould and Fowler 1991), which may have a similar function to metallothioneins (metal-binding proteins) from other bivalves. Sub-cellular particles in kidney cells of *P. magellanicus* can bind metals such as cadmium and reduce their toxicity (Fowler and Gould 1988). The species has also been suggested to have the ability to develop mixed-function oxidase enzymes to detoxify various organic compounds.

Responses of *P. magellanicus* to exposures to contaminants can be measured by assessment of overall energy balance and metabolism (e.g. scope for growth, the energy available for growth), as well as by tests for enzymes which indicate energy state (e.g. Gould 1981). In some cases, tissue damage has been evaluated to ascribe impacts of contaminants on specific changes in the functioning of the organism (e.g. Yevich and Yevich 1985).

Metals

<u>**Sources**</u>: Except where they occur in geological formations, heavy metals exist naturally in the environment in low concentrations. Some of these (e.g. lead, cadmium, and mercury) do not appear to serve biological functions, while others (e.g. copper and zinc) are constituents of essential enzymes, vitamins, and proteins.

Metal pollution of offshore scallop populations is not generally a concern in eastern Canadian waters, although localized occurrences of metal pollution do occur through releases of metals from drilling muds and wastes, and, especially off densely populated areas of the east coast of the United States, in sewage disposed offshore. Various metals occur in sewage sludge, but the most likely to impact marine organisms is copper because of its acute toxicity (Santoro and Fikslin 1987). Dumping of sewage in offshore waters, as occurs in other nations, is not practised in eastern Canada.

Scallops in industrialized coastal areas of eastern Canada can be exposed to heavy metals chiefly from mining activities, industrial and urban sewage discharges, wastes from marine ship repair and construction, painted coastal structures such as bridges, freshwater inputs, natural mineral formations, and airborne contaminants. Wharves using Wolmanized[R] lumber add chromium, copper, and arsenic (from chromated copper arsenate) (Weis et al. 1992).

Mining and related activities of smelting, shipping, loading, and unloading have led to elevated metal concentrations in surficial sediments and have impacted fishery resources in the Baie des Chaleurs. The lead smelter at Belledune, on the New Brunswick coast of Baie des Chaleurs, and the associated cadmium in effluent resulted in high levels of Cadmium in *P. magellanicus* (Ray et al. 1984), and elevated metal levels in scallops have been observed near ore-loading and storage facilities in Newfoundland (Naidu 1991).

Scallops from relatively pristine areas such as Georges Bank and other offshore areas south of Nova Scotia and in the Gulf of Maine can have relatively high cadmium concentrations (in some cases greater than in scallops from the Baie des Chaleurs where metal contamination is a concern). Natural sources as well as starvation during parts of the year have been suggested as the cause of the elevated cadmium concentrations (Uthe and Chou 1987; Gould and Fowler 1991).

<u>Accumulation and Effects</u>: In sea scallops, metals are typically concentrated mainly in the digestive gland, but significant concentrations can also occur in the kidney (Uthe and Chou 1987). Presence of other metals can influence accumulation; for example, the presence of cadmium appears to lead to greater accumulation of copper than if copper is present alone.

The species appears to be sensitive to metal exposure, based on studies focusing principally on copper and cadmium. *P. magellanicus* is highly sensitive to copper, and exposures to low concentrations cause scallops to cease filtering, to reduce production and maturation of gametes, and eventually to die (Gould et al. 1989a; 1989b). Concentrations of copper at 10 to 20 ppb damage digestive, gonad, and kidney tissues and lead to loss of solid particles (concretions), known to moderate metal exposures, from kidney cells (Gould and Fowler 1991; Yevich and Yevich 1985). Exposure of sea scallops to cadmium at 10 to 20 ppb does not have as severe an effect as for copper but can result in early maturation of gonads and early use of energy storage compounds from the muscle (Gould and Fowler 1991). Sea scallops can recover from cadmium exposure, but copper apparently causes permanent damage to kidney tissues (Yevich and Yevich 1985).

Organic Contaminants

Sea scallops in eastern Canada can be exposed to a wide range of organic contaminants in coastal waters (e.g. PAHs, PCBs, pesticides, hydrocarbons, and various other contaminants), while offshore populations are most likely to encounter hydrocarbons resulting from offshore exploration and production activity (see "Hydrocarbon Industry" section below). Offshore populations of *P. magellanicus* from the east coast of the United States may be exposed to various organic contaminants found in sewage and other contaminated wastes disposed offshore.

Few studies have examined organic contamination of scallops in Canadian coastal waters. *P. magellanicus* does not show concentrations of the polychlorinated pesticide toxaphene (Musial and Uthe 1983). In Newfoundland waters, sea scallops have negligible hydrocarbon and PAH concentrations in the viscera (Hellou et al. 1993). In contrast, sea scallops in New York Bight showed significant concentrations of PAHs in adductor muscles (Humason and Gadbois 1982).

PHYSICAL DISTURBANCE

Dredging and Ocean Dumping

Ocean dumping may affect local scallop populations by burial, by increasing suspended sediment levels, and by causing reduced oxygen concentrations in the water column. The mobility of scallops gives them some ability to free themselves of minor loadings of dumped material, the larger scallops having the greatest ability to do so. Suspended levels caused by ocean dumping are comparable to those to which scallops would be exposed from sediment resuspension during extreme storms, and would be of short duration and therefore not have a significant impact on scallops (Seakem Oceanography Limited 1991). Scallops are likely to be more sensitive to prolonged elevations of suspended material (concentrations on the order of 10 mg/L), particularly if the sediment is fine (Cranford and Gordon 1992).

Commercial Fishing Activity

Commercial fishing activity, including groundfish trawls and scallop dragging, has significant impacts on the seabed and associated communities (Messieh et al. 1991). Impacts attributed to scallop dragging include: increases in near-bottom suspended sediment concentrations, disturbed surface sediments, removal or alteration of invertebrate communities, damage to other commercial species, and altered feeding relations (e.g. discarded viscera, as well as other organisms damaged and left vulnerable by the dredge). Inshore scallop dragging does not appear to impact the commercial lobster fishery in Nova Scotia; in most areas fishing areas for the two species do not overlap, and where they do co-occur in commercial abundance, losses of lobster due to scallop dragging are insignificant (Roddick and Miller 1992).

Damage to scallops from commercial dragging operations appears to be small, and estimates of mortality from field studies range from 5 to 17% of uncaught scallops, depending on bottom type (Caddy 1973; Murawski and Serchuk 1989). In sandy bottom areas of the Gulf of St. Lawrence, dredge-induced mortality of scallops can be 5% but is higher on rocky ground. In rocky areas, scallops may be crushed by the dredge and by rocks dislodged from the dredge path (Caddy 1973; Shepard and Auster 1991).

Catch handling practices such as dumping on deck, culling, shovelling, deck-loading, cold and warm temperature shock, and air exposure can also induce mortality in undersized scallops which are returned to the sea. If handled carefully, however, a large proportion of undersized scallops can survive; culling mortality of scallops has been estimated at less than 10%. A major die-off indicated by a high incidence of empty shells still hinged together ("clappers") in 1989 in Cape Spencer, New Brunswick, was attributed to fishing pressure (Robinson et al. 1992).

Dragging can also alter food chain relationships and impact community structure. Predatory fish and crabs are attracted to dredge tracks and may occur at densities 3 to 30 times greater inside than outside the dredge path (Caddy 1973). These predators may contribute indirectly to scallop mortality attributed to the dredge (Shepard and Auster 1991). Productive scallop beds in the Gulf of Maine, which had been dragged, differed in associations of invertebrates; and some natural associations ceased to occur in dragged areas (Langton and Robinson 1990). The practice of shucking at sea can provide a food source for seabed communities. Invertebrate predators such as starfish have been observed consuming scallop viscera cast from fishing vessels, while finfish surveys have revealed significant quantities of scallop viscera in fish stomachs (Murawski and Serchuk 1989).

Scallop dredging can mix bottom sediments and alters the distribution of sediment organic matter by moving it horizontally or by mixing it into subsurface sediments. Other potential impacts include rapid release of nutrients into the water column and disruption of vertical zonation of organic matter in the sediments (Mayer et al. 1991), but resultant impacts on scallops are probably minor. Commercial scallop harvesting or dragging also causes local elevations in suspended sediment loads, but the resuspended material generally settles within minutes to hours and may not result in a significant impact on scallops.

INDUSTRIAL CONTAMINATION

Coastal populations of sea scallops are most likely to be impacted by industrial pollution. As the species is relatively sedentary, scallops cannot avoid major episodes of environmental contamination. An extreme case of damage to a scallop population occurred in 1969 when effluent from a phosphorus plant in Placentia Bay, Newfoundland, resulted in complete mortality of scallops within 300 m of the outfall and some mortalities up to 1 km from the site (Gould and Fowler 1991).

Pulp and Paper

The pulp and paper industry typically causes reductions in dissolved oxygen concentration through elevated biological oxygen demand (BOD) of plant effluents. Dioxins and furans (by-products of chlorine bleaching and contained in some process chemicals) are not allowed in pulp mill effluents; and BOD suspended solids are presently regulated under the Pulp and Paper Regulations of the Canadian Environmental Protection Act and the Fisheries Act. Effluent from pulp mills has a dark colour and low salinity and may impact primary production in the water column. Mercury releases from the processes used to produce chlorine for bleaching were formerly a primary concern in connection with the pulp and paper industry but have been controlled. Apparently healthy sea scallop populations occur downstream of pulp and paper operations: in the St. Croix estuary, New Brunswick (where pulp mills occur on the St. Croix River in Maine); and in the outer harbour and mouth of L'Etang

Inlet, New Brunswick, where the inner harbour has been severely impacted by pulp mill operations.

Mining and Related Activities

Mining, smelting, and ore-loading operations impact marine environments chiefly through release of effluents having elevated metal concentrations and turbidity. Contaminants include metals and organics (e.g. PAHs) from combustion processes involved in smelting. Prior to emission controls and plant modifications, the Brunswick Mining and Smelting lead smelter at Belledune, New Brunswick, produced effluents having elevated levels of cadmium and lead, leading to localized occurrence of these metals in scallops and lobster in the vicinity and downstream from the site (Ray et al. 1980; Ray et al. 1984). Levels of lead, zinc, and copper were also found in scallops close to ore storage and loading facilities in Newfoundland (Naidu 1991).

Chlorination

Scallops (adults and larvae) can be impacted if exposed to chlorine-produced oxidants resulting from fouling treatments to industrial cooling water discharges (typically thermal electric-generating plants) and chlorinated sewage. Although major commercial scallop populations are not found commonly in coastal areas where they would be likely exposed to chlorine discharges, or entrained in treated cooling water, local populations could suffer impacts. Chlorine reacts chemically with seawater and organic matter and rapidly dilutes, and generally the resident populations of adult organisms would rarely be impacted directly by chlorinated effluents. Scallop larvae may be impacted by being drawn through treated cooling water systems or by contacting chemicals produced by chlorine compounds on reacting with organics in seawater (e.g. halomethanes).

Thermal Pollution

Scallops are particularly sensitive to elevated temperatures and sudden temperature changes (Dickie 1958; Gould and Fowler 1991). Although most significant beds occur in offshore areas, local beds occurring in the vicinity of intakes and outfalls of thermal electric and nuclear power facilities should be considered to be a concern unless mixing is at all times sufficient to ensure acceptable temperatures for scallops.

Hydrocarbon Industry

Scallop stocks in eastern Canada can be impacted by exploration and production activity for hydrocarbons, as well as by accidental spillage and loss of hydrocarbons during transport. Hydrocarbon potential has been identified for Georges Bank, the site of the major east coast scallop stock, although a current moratorium on exploration will be in place until the year 2000. Natural gas condensate is currently produced southwest of Sable Island on the Panuke/Cohasset field. The remaining hydrocarbon production activity in eastern Canada centres on the Hibernia discovery on the Grand Banks, where no significant sea scallop populations occur.

Potential impacts on sea scallops from exploratory and production activity on Georges Bank could include mortalities, population and community level changes, and tainting, resulting from accidental spills of hydrocarbons as well as normal releases of production-related materials such as drilling muds and "production" water. Georges Bank may be especially susceptible to accidental spills, including those from tanker accidents, since the tidal gyre on the Bank may keep spilled hydrocarbons in the vicinity of the Bank; and high vertical mixing rates caused by strong tidal currents could readily convey them to the seafloor (Gordon 1988).

Hydrocarbon exposure can have immediate impacts on egg, larval, and adult stages of scallops as occurs for various other organisms. For example, the *Argo Merchant* spill off the coast of the United States resulted in scallops having depressed gill respiration 3 wk after the spill (Gould and Fowler 1991). Hydrocarbons have also been found in tissues of *P. magellanicus* near the site of a Rhode Island gasoline spill (Ibid.). In many aquatic organisms exposed to hydrocarbons (and likely in *P. magellanicus* as well), highest mortalities and most significant effects occur in egg and larval stages; but recovery is often possible even after moderate exposures if conditions return to normal. Information on toxic effects of hydrocarbons in scallops is lacking.

Drilling muds, which are used normally to lubricate the drill bit, to stabilize the borehole, and to carry rock cuttings to the surface, are a major waste product of drilling operations having the potential to impact scallops. Although muds and cuttings are unlikely to bury scallops, solid drilling wastes outside the immediate vicinity of the drilling platform may impact them by causing chemical contamination and physical effects, such as impairment of feeding. *P. magellanicus* can also concentrate barium and chromium from drilling muds, typically in the kidney and digestive gland (Gilbert et al. 1985), and is sensitive to fine clay particles, even at low concentrations. Scallops resting on mineral oil-based drilling muds show increased mortalities, reduction in growth, decreased condition indices, and failure to accumulate lipid reserves (Cranford and Gordon 1991). Bentonite clay (a major component of drilling muds) leads to mortality under prolonged exposures at concentrations in suspension of as little as 10 mg/L (Cranford and Gordon 1992). Clays appear to impair the action of cilia which cause feeding currents. High concentrations of particulate material (clays at 500 to 1000 mg/L), although unlikely to be encountered by *P. magellanicus*, can physically damage the gill and lead to death (Morse et al. 1982). Nevertheless, sea scallops can recover from exposures to fine material if suspended levels are returned to normal. Drilling mud suspensions also cause mortality of larval scallops; and shell formation is inhibited in early larval scallops by exposure to chrome lignosulfonate, one of the chemical binders used in drilling muds (Gould and Fowler 1991).

Sea scallops will also accumulate taint (an atypical flavour or odour) in the adductor muscle as a result of exposure to hydrocarbons, although the concentrations required to induce tainting are unlikely to occur in the event of a blow-out and do not cause mortalities of the scallops. Concentrations as low as 0.5 ppm and 0.8 ppm in the water-soluble fraction (WSF) of a typical crude oil and Scotian Shelf natural gas condensate respectively can cause tainting in 3 to 96 h. The taint could be removed by depurating the scallops in clean water. The main hydrocarbons in tainted meats appear to be toluene and xylene, but a range of organic compounds are present (Carter and Ernst 1989).

Coastal and Offshore Structures

Commercial stocks of *P. magellanicus* occur in the vicinity of the proposed "Fixed Link" bridge crossing Northumberland Strait between Cape Tormentine, New Brunswick, and Borden, Prince Edward Island. Environmental assessments of the project have estimated that the Fixed Link will displace only a small number of scallops and probably cause only minor elevations in suspended sediment, thus not impacting scallop habitat directly. Minor impacts on current regime (slowing of the residual circulation and increasing vertical mixing) are not believed to be large enough to disrupt current gyres suspected in maintaining scallop and herring populations in the area. Delays in ice-out, which will in turn delay spring warming of the water temperatures in the Strait, could reduce scallop growth and ultimately reduce landings. The bridge could interfere with scallop dragging in its immediate vicinity.

AGRICULTURAL AND FORESTRY IMPACTS

Agricultural and forestry practices introduce suspended sediment into coastal waters and can lead to the introduction of pesticides, fertilizers, and fecal coliform bacteria. In many areas, fecal coliforms from livestock operations wash into coastal waters in periods of high run-off, cause conditional closures of shellfish beds, and limit sites available to aquaculture. Scallops are relatively intolerant of suspended particulate matter, and populations in coastal areas could be impacted by elevated SPM levels. Commercial scallop populations do occur in the St. Croix River estuary, which is influenced by heavy forest and some agricultural chemical usage, although mortalities of scallops are unlikely.

SEWAGE AND FECAL CONTAMINATION

Coastal contamination with sewage or coliform bacteria is generally not a problem in connection with major commercial scallop populations but does limit the utilization of areas along the coast in which aquaculture operations are permitted. Aquaculture operations are not usually permitted in closed areas, but provision for depuration of aquacultured shellfish in marginally contaminated areas has been proposed. Closure areas do not prevent recreational use of scallops as the meat is not contaminated with fecal coliforms. Shellfish harvesting (including scallops) is under conditional closure in the upper St. Croix River estuary, New Brunswick.

Low oxygen conditions caused massive mortalities of scallops and other resource species in offshore areas of the east coast of the United States as a result of a combination of human contamination from sewage and waste dumping, early warming of surface waters, the subsequent early development of a thermocline, plus a massive and persistent phytoplankton bloom within 100 km of the coast (Gould and Fowler 1991; Murawski et al. 1989).

HYDROELECTRIC DEVELOPMENT

Hydroelectric development (dams and diversions) can result in changes to flow regime in some marine areas. Changes in the freshwater flow, such as levelling through the season or sudden releases, can influence patterns of biological productivity in coastal waters, particularly estuaries (see Skreslet 1985). Scallop populations do not occur in the St. Lawrence River estuary where broad ecosystem impacts resulting from existing or proposed hydroelectric generation projects have been predicted, but are found in many other coastal areas influenced by smaller levels of freshwater control (e.g. St. Croix River estuary, New Brunswick, and in many coastal areas of Newfoundland). In these areas, low salinities and changes to the physical oceanography could impact natural and aquacultured populations of scallops by instituting ecosystem changes, although direct mortality of scallops due to low salinity is not likely to occur.

ACKNOWLEDGEMENTS

This technical report was prepared by Envirosphere Consultants Limited under a contract by the Habitat Ecology Division of the Department of Fisheries and Oceans. The authors would like to acknowledge the assistance of Mr. H. Brian Nicholls and Dr. Donald C. Gordon, as well as Mr. Peter Cranford, Ms. Leslie-Anne Davidson, Mr. Michel Giguère, Dr. Ellen Kenchington, Mr. K.S. Naidu, Mr. Randy Penney, and Drs. S. Ray and Ginette Robert, all from the Department of Fisheries and Oceans. Ms. Patty Kendrick and Mr. Ken Meade assisted with collection and management of background information.

BIBLIOGRAPHY

General:

Black, G.A.P., R.K. Mohn, G. Robert, and M.J. Tremblay. 1993. Atlas of the biology and distribution of the sea scallop *Placopecten magellanicus* and Iceland scallop *Chlamys islandica* in the Northwest Atlantic. Can. Tech. Rep. Fish. Aquat. Sci. 1915: 40 p.

MacKenzie, C.L., Jr. 1979. Biological and fisheries data on sea scallop, *Placopecten magellanicus* (Gmelin). U.S. Dept. of Commerce, NMFS, Tech. Ser. Rep. 19.

Naidu, K.S. 1991. Sea scallop, *Placopecten magellanicus*, p. 861-897. In S.E. Shumway [ed.]. Scallops: Biology, ecology and aquaculture. Developments in Aquaculture and Fisheries Sciences 21. Elsevier Science Publishing, B.V., Amsterdam. 1,095 p.

Shumway, S.E. [ed.]. 1991. Scallops: Biology, ecology and aquaculture. Developments in Aquaculture and Fisheries Sciences 21. Elsevier Science Publishing, B.V., Amsterdam. 1,095 p.

Stocks and Biology:

Beninger, P.G. 1991. Structures and mechanisms of feeding in scallops: Paradigms and paradoxes, p. 331-340. In S.E. Shumway and P.A. Sandifer [ed.]. An international compendium of scallop biology and culture. World Aquaculture Workshops, No. 1. 7th International Pectinid Workshop, World Aquaculture Society.

Brand, A.R. 1991. Scallop ecology: Distributions and behaviour, p. 517-584. In S.E. Shumway [ed.]. Scallops: Biology, ecology and aquaculture. Developments in Aquaculture and Fisheries Sciences 21. Elsevier Science Publishing, B.V., Amsterdam. 1,095 p.

Culliney, J.L. 1974. Larval development of the giant scallop *Placopecten magellanicus* (Gmelin). Biol. Bull. 147: 321-332.

Getchell, R.G. 1991. Diseases and parasites of scallops, p. 471-494. In S.E. Shumway [ed.]. Scallops: Biology, ecology and aquaculture. Developments in Aquaculture and Fisheries Sciences 21. Elsevier Science Publishing, B.V., Amsterdam. 1,095 p.

McGladdery, S.E., R.E. Drinnan, and M.F. Stephenson. 1993. A manual of parasites, pests and diseases of Canadian Atlantic bivalves. Can. Tech. Rep. Fish. Aquat. Sci. 1931: 121 p.

Parsons, G.J., S.M.C. Robinson, R.A. Chandler, L.A. Davidson, M. Lanteigne, and M.J. Dadswell. 1992. Intra-annual and long-term patterns in the reproductive cycle of giant scallops (*Placopecten magellanicus*) from Passamaquoddy Bay, New Brunswick, Canada. Mar. Ecol. Prog. Ser. 80: 203-214.

Thompson, R.J., and B.A. MacDonald. 1990. The role of environmental conditions in the seasonal synthesis and utilisation of biochemical energy reserves in the giant scallop, *Placopecten magellanicus*. Can. J. Zool. 68: 750-756.

Thouzeau, G., G. Robert, and S.J. Smith. 1991. Spatial variability in distribution and growth of juvenile and adult sea scallops *Placopecten magellanicus* (Gmelin) on eastern Georges Bank (Northwest Atlantic). Mar. Ecol. Prog. Ser. 74: 205-218.

Thouzeau, G., G. Robert, and R. Ugarte. 1991. Faunal assemblages of benthic megainvertebrates inhabiting sea scallop grounds from eastern Georges Bank, in relation to environmental factors. Mar. Ecol. Prog. Ser. 74: 61-82.

Tremblay, M.J., and M. Sinclair. 1992. Planktonic sea scallop larvae (*Placopecten magellanicus*) in the Georges Bank region: Broadscale distribution in relation to physical oceanography. Can. J. Fish. Aquat. Sci. 49: 1597-1615.

<u>Aquaculture</u>:

Carter, P., and P. Béland. 1984. L'aquiculture marine au Québec. Rapp. tech. can. sci. halieut. aquat. 1315: xi + 85 p.

Dadswell, M.J., and G.J. Parsons. 1991. Potential for aquaculture of sea scallop, *Placopecten magellanicus* (Gmelin, 1791) in the Canadian Maritimes using naturally produced spat, p. 300-307. <u>In</u> S.E. Shumway and P.A. Sandifer [ed.]. An international compendium of scallop biology and culture. World Aquaculture Workshops, No. 1. 7th International Pectinid Workshop, World Aquaculture Society.

Naidu, K.S., and F. Cahill. 1986. Culturing giant scallops in Newfoundland waters. Can. Muscr. Rep. Fish. Aquat. Sci. 1876: iv + 23 p.

Shumway, S.E., and P.A. Sandifer [ed.]. 1991. An international compendium of scallop biology and culture. World Aquaculture Workshops, No. 1. 7th International Pectinid Workshop, World Aquaculture Society.

Young-Lai, W.W., and D.E. Aiken. 1986. Biology and culture of the giant scallop, *Placopecten magellanicus*: A review. Can. Tech. Rep. Fish. Aquat. Sci. 1478.

Industrial Pollution and Contaminants:

Carter, J., and R. Ernst. 1989. Tainting in sea scallops (*Placopecten magellanicus*) exposed to the water-soluble fraction of crude oil and natural gas condensate, p. 149-159. In Proceedings of the 12th Arctic and Marine Oil Spill Program Technical Seminar. Environ. Can., Ottawa, Ont.

Cranford, P.J., and D.C. Gordon, Jr. 1991. Chronic sublethal impact of mineral oil-based drilling mud cuttings on adult sea scallops. Mar. Poll. Bull. 22: 339-344.

Fowler, B.A., and E. Gould. 1988. Ultrastructural and biochemical studies of intracellular metal-binding patterns in kidney tubule cells of the scallop *Placopecten magellanicus* following prolonged exposure to cadmium or copper. Mar. Biol. 97: 207-216.

Gould, E., and B.A. Fowler. 1991. Scallops and pollution, p. 495-515. In S.E. Shumway [ed.]. Scallops: Biology, ecology and aquaculture. Developments in Aquaculture and Fisheries Sciences 21. Elsevier Science Publishing, B.V., Amsterdam. 1,095 p.

Uthe, J.F., and C.L. Chou. 1987. Cadmium in sea scallop (*Placopecten magellanicus*) tissues from clean and contaminated areas. Can. J. Fish. Aquat. Sci. 44: 91-98.

Yevich, C.A., and P.P. Yevich. 1985. Histopathological effects of cadmium and copper on the sea scallop *Placopecten magellanicus*, p. 187-198. In F.J. Vernberg, F.P. Thurberg, A. Calabrese, and W. Vernberg [ed.]. Marine pollution and physiology: recent advances. The Belle W. Baruch Library in Marine Science 13. University of South Carolina Press.

Dredging and Ocean Dumping:

Messieh, S.N., T.W. Rowell, D.L. Peer, and P.J. Cranford. 1991. The effects of trawling, dredging and ocean dumping on the eastern Canadian continental shelf seabed. Cont. Shelf Res. 11: 1237-1263.

Seakem Oceanography Limited. 1991. Assessment of the effects of suspended dredge material on aquaculture organisms. Ocean Dumping Rep. 8, Environ. Can., Atlantic Region.

Other:

Dickie, L.M. 1958. Effects of high temperature on survival of the giant scallop. J. Fish. Res. Board Can. 15: 1189-1211.

Jamieson, G.S., and R.A. Chandler. 1983. Paralytic shellfish poison in sea scallops (*Placopecten magellanicus*) in the west Atlantic. Can. J. Fish. Aquat. Sci. 40: 313-318.

DEPARTMENT OF FISHERIES AND OCEANS EXPERTS

Ecology, Distribution, and Fisheries	Lesley-Ann Davidson[1]	(506) 851-6133
	Peter Cranford[2]	(902) 426-3277
	Michel Giguère[3]	(418) 775-0622
	Ellen Kenchington[4]	(902) 426-2030
	Sam Naidu[5]	(709) 772-2091
	Ginette Robert[4]	(902) 426-2616
Aquaculture	Randy Penney[5]	(709) 772-4704
	Sam Naidu[5]	(709) 772-2091
Contaminants	Jack Uthe[4]	(902) 426-6277
	Vlado Zitko[6]	(506) 529-8854
Parasites	Sharon McGladdery[1]	(506) 851-2018

---

[1]Department of Fisheries and Oceans
Gulf Fisheries Centre
P.O. Box 5030
Moncton, NB E1C 9B6
Canada

[2]Department of Fisheries and Oceans
Bedford Institute of Oceanography
P.O. Box 1006
Dartmouth, NS B2Y 4A2
Canada

[3]Department of Fisheries and Oceans
Institut Maurice Lamontagne
P.O. Box 1000
Mont-Joli, PQ G5H 3Z4
Canada

[4]Department of Fisheries and Oceans
Halifax Fisheries Research Laboratory
P.O. Box 550
Halifax, NS B3J 2S7
Canada

[5]Department of Fisheries and Oceans
Northwest Atlantic Fisheries Centre
P.O. Box 5667
St. John's, NF A1C 5X1
Canada

[6]Department of Fisheries and Oceans
St. Andrews Biological Station
Brandy Cove Road
St. Andrews, NB E0G 2X0
Canada

REFERENCES

Barber, B.J., R. Getchell, S. Shumway, and D. Schick. 1988. Reduced fecundity in a deep-water population of the giant scallop *Placopecten magellanicus* in the Gulf of Maine, U.S.A. Mar. Ecol. Prog. Ser. 42: 207-212.

Bayne, B.L., D.A. Brown, K. Burns, D.R. Dixon, A. Ivanovici, D.R. Livingstone, D.M. Lowe, M.N. Moore, A.R.D. Stebbing, and J. Widdows. 1985. The effects of stress and pollution on marine animals. Praeger, New York. 384 p.

Beninger, P.G. 1991. Structures and mechanisms of feeding in scallops: Paradigms and paradoxes, p. 331-340. In S.E. Shumway and P.A. Sandifer [ed.]. An international compendium of scallop biology and culture. World Aquaculture Workshops, No. 1. 7th International Pectinid Workshop, World Aquaculture Society.

Black, G.A.P., R.K. Mohn, G. Robert, and M.J. Tremblay. 1993. Atlas of the biology and distribution of the sea scallop *Placopecten magellanicus* and Iceland scallop *Chlamys islandica* in the Northwest Atlantic. Can. Tech. Rep. Fish. Aquat. Sci. 1915: 40 p.

Bohlen, W.F., D.F. Cundy, and J.M. Tramontano. 1979. Suspended material distributions in the wake of estuarine channel dredging operations. Estuarine Coastal Mar. Sci. 9: 699-711.

Bothner, M.H., C.M. Parmenter, and J.D. Milliman. 1981. Temporal and spatial variations in suspended matter in continental shelf and slope waters off the northeastern United States. Estuarine Coastal Shelf Sci. 13: 213-234.

Bourne, N. 1964. Scallops and the offshore fisheries of the Maritimes. Bull. Fish. Res. Board Can. 145: 60 p.

Brand, A.R. 1991. Scallop ecology: Distributions and behaviour, p. 517-584. In S.E. Shumway [ed.]. Scallops: Biology, ecology and aquaculture. Developments in Aquaculture and Fisheries Sciences 21. Elsevier Science Publishing, B.V., Amsterdam. 1,095 p.

Caddy, J.F. 1972. Progressive loss of byssus attachment with size in the sea scallop, *Placopecten magellanicus* (Gmelin). J. Exp. Mar. Biol. Ecol. 9: 179-190.

-------------- 1973. Underwater observations on scallop (*Placopecten magellanicus*) behaviour and drag efficiency. J. Fish. Res. Board Can. 25: 2123-2411.

CAFSAC (Canadian Atlantic Fisheries Scientific Advisory Committee). 1992. Scallops on Georges Bank (NAFO Subdivision 5Zc). Can. Atl. Fish. Sci. Adv. Comm. Doc. 92/5.

Carter, P., and P. Béland. 1984. L'aquiculture marine au Québec. Rapp. tech. can. sci. halieut. aquat. 1315: xi + 85 p.

Carter, J., and R. Ernst. 1989. Tainting in sea scallops (*Placopecten magellanicus*) exposed to the water-soluble fraction of crude oil and natural gas condensate, p. 149-159. In Proceedings of the 12th Arctic and Marine Oil Spill Program Technical Seminar. Environ. Can., Ottawa, Ont.

Chouinard, G.A., and P.V. Mladenov. 1991. Comparative growth of the sea scallop (*Placopecten magellanicus*) in the southern Gulf of St. Lawrence. Can. Spec. Publ. Fish. Aquat. Sci. 113.

Cranford, P.J., and J. Grant. 1990. Particle clearance and absorption of phytoplankton and detritus by the sea scallop *Placopecten magellanicus* (Gmelin). J. Exp. Mar. Biol. Ecol. 137: 105-121.

Cranford, P.J., and D.C. Gordon, Jr. 1991. Chronic sublethal impact of mineral oil-based drilling mud cuttings on adult sea scallops. Mar. Poll. Bull. 22: 339-344.

Cranford, P.J., and D.C. Gordon, Jr. 1992. The influence of dilute clay suspensions on sea scallop (*Placopecten magellanicus*) feeding activity and tissue growth. Neth. J. Sea Res. 30: 107-120.

Culliney, J.L. 1974. Larval development of the giant scallop *Placopecten magellanicus* (Gmelin). Biol. Bull. 147: 321-332.

Dadswell, M.J., and G.J. Parsons. 1991. Potential for aquaculture of sea scallop, *Placopecten magellanicus* (Gmelin, 1791) in the Canadian Maritimes using naturally produced spat, p. 300-307. In S.E. Shumway and P.A. Sandifer [ed.]. An international compendium of scallop biology and culture. World Aquaculture Workshops, No. 1. 7th International Pectinid Workshop, World Aquaculture Society.

Davidson, L.-A., M. Lanteigne, and M. Niles. 1993. Timing of the gametogenic development and spawning period of the giant scallop *Placopecten magellanicus* (Gmelin) in the southern Gulf of St. Lawrence. Can Tech. Rep. Fish. Aquat. Sci. 1935: 14 p.

Dibacco, C. 1993. Reproductive cycle of the giant sea scallop, *Placopecten magellanicus* (Gmelin) on northeastern Georges Bank. M.Sc. Thesis, Dalhousie University, Halifax, N.S. 78 p.

Dickie, L.M. 1958. Effects of high temperature on survival of the giant scallop. J. Fish. Res. Board Can. 15: 1189-1211.

Dickie, L.M., and J.C. Medcof. 1963. Causes of mass mortalities of scallops (*Placopecten magellanicus*) in the southwestern Gulf of St. Lawrence. J. Fish. Res. Board Can. 20: 451-482.

Fowler B.A., D.W. Engel, and E. Gould. 1985. Ultrastructural and biochemical effects of prolonged cadmium and copper exposure on kidneys of the scallop *Placopecten magellanicus*. Mar. Environ. Res. 17: 199.

Fowler, B.A., and E. Gould. 1988. Ultrastructural and biochemical studies of intracellular metal-binding patterns in kidney tubule cells of the scallop *Placopecten magellanicus* following prolonged exposure to cadmium or copper. Mar. Biol. 97: 207-216.

Fréchette, M. 1989. Effet de l'orientation au courant sur la croissance du pétoncle géant, *Placopecten magellanicus* (Gmelin). Naturaliste Can. 116: 79-85.

Getchell, R.G. 1991. Diseases and parasites of scallops, p. 471-494. In S.E. Shumway [ed.]. Scallops: Biology, ecology and aquaculture. Developments in Aquaculture and Fisheries Sciences 21. Elsevier Science Publishing, B.V., Amsterdam. 1,095 p.

Giguère, M., G. Cliche, and S. Brulotte. 1994. Reproductive cycles of the sea scallop, *Placopecten magellanicus*, and the Iceland scallop, *Chlamys islandica*, off Iles-de-la-Madeleine. J. Shellfish Res. 13: 31-37.

Gilbert, T.R., B.A. Penney, R.G. Liss, and D.A. Wayne. 1985. Availability of trace metals in drilling fluids, p. 271-288. In I.W. Duedall, D.R. Kester, P.K. Park, and B.H. Ketchum [ed.]. Wastes in the Ocean 4. Energy Wastes in the Ocean.

Gillis, M., C. Surette, D. Richard, and W. Watson-Wright. 1991. Escalation of paralytic shellfish poisoning in viscera of Georges Bank scallops (*Placopecten magellanicus*) from 1988-1990, p. 9. In D.C. Gordon, Jr. [ed.]. Proceedings of the Second Canadian Workshop on Harmful Marine Algae. Bedford Institute of Oceanography, Dartmouth, N.S., October 2-4, 1990. Can. Tech. Rep. Fish. Aquat. Sci. 1799: 66 p.

Gordon, D.C. 1988. An assessment of the possible environmental impacts of exploratory drilling on Georges Bank fisheries resources. Can. Tech. Rep. Fish. Aquat. Sci. 1633: iv + 31 p.

Gould, E. 1981. Field stress in the scallop *Placopecten magellanicus*. Int. Counc. Explor. Sea C.M.1981/E:7: 11 p.

Gould, E., R.J. Thompson, and L.J. Buckley. 1989a. Exposure of the scallop *Placopecten magellanicus* (Gmelin) to sublethal copper and cadmium: Effects on the reproductive effort. Mar. Environ. Res. 28: 288.

Gould, E., B.A. Fowler, and D.W. Engel. 1989b. Metal-exposed sea scallops: A review and update of the effects of copper, cadmium and zinc. Mar. Environ. Res. 28: 219-223.

Gould, E., and B.A. Fowler. 1991. Scallops and pollution, p. 495-515. In S.E. Shumway [ed.]. Scallops: Biology, ecology and aquaculture. Developments in Aquaculture and Fisheries Sciences 21. Elsevier Science Publishing, B.V., Amsterdam. 1,095 p.

Grant, J., and P.J. Cranford. 1991. Carbon and nitrogen scope for growth as a function of diet in the sea scallop *Placopecten magellanicus*. J. Mar. Biol. Assoc. U.K. 71: 437-450.

Grant, J., A. Hatcher, D.B. Scott, P. Pocklington, C.T. Schafer, and G.V. Winters. In press. A multidisciplinary approach to evaluating benthic impacts of shellfish aquaculture. Estuaries.

Hatcher, B.G., R.E. Scheibling, M.A. Barbeau, A.W. Henniger, L.H. Taylor, and A.J. Windust. In press. Dispersion and mortality of a population of the sea scallop, *Placopecten magellanicus*, seeded in a tidal channel. Can. J. Fish. Aquat. Sci.

Hawryluk, M., P. Schwinghamer, C. Powell, and C.H. MacKenzie. 1992. Winter occurrence of PSP in inshore Newfoundland waters is caused by resuspended hypnozygotes of *Alexandrium fundyense*, p. 13-14. In J.-C. Therriault, and M. Levasseur [ed.]. Proceedings of the Third Canadian Workshop on Harmful Marine Algae. Can. Tech. Rep. Fish. Aquat. Sci. 1893: 154 p.

Haya, K., W.W. Young-Lai, J.E. Stewart, and J.F. Jellett. 1992. Uptake and excretion of paralytic shellfish toxin by lobster fed scallop digestive glands, p. 38. In J.-C. Therriault and M. Levasseur [ed.]. Proceedings of the Third Canadian Workshop on Harmful Marine Algae. Can. Tech. Rep. Fish. Aquat. Sci. 1893: 154 p.

Hellou, J., C. Upshall, J.F. Payne, S. Naidu, and M.A. Paranjape. 1993. Total unsaturated compounds and polycyclic aromatic hydrocarbons in molluscs collected from waters around Newfoundland. Arch. Environ. Contam. Toxicol. 24: 249-257.

Humason, A.W., and D.F. Gadbois. 1982. Determination of polynuclear aromatic hydrocarbons in the New York Bight area. Bull. Environ. Contam. Toxicol. 29: 645-650.

Jamieson, G.S., H. Stone, and M. Etter. 1982. Predation of sea scallops (*Placopecten magellanicus*) by lobsters (*Homarus americanus*) and rock crabs (*Cancer irroratus*) in underwater cage enclosures. Can. J. Fish. Aquat. Sci. 39: 499-505.

Jamieson, G.S., and R.A. Chandler. 1983. Paralytic shellfish poison in sea scallops (*Placopecten magellanicus*) in the West Atlantic. Can. J. Fish. Aquat. Sci. 40: 313-318.

Langton, R.W., and W.E. Robinson. 1990. Faunal associations on scallop grounds in the western Gulf of Maine. J. Exp. Mar. Biol. Ecol. 144: 157-171.

MacDonald, B.A. and C.D. Bajdik. 1992. Orientation and distribution of individual *Placopecten magellanicus* (Gmelin) in two natural populations with differing production. Can. J. Fish. Aquat. Sci. 49: 2086-2092.

MacKenzie, C.L., Jr. 1979. Biological and fisheries data on sea scallop, *Placopecten magellanicus* (Gmelin). U.S. Dept. of Commerce, NMFS Tech. Ser. Rep. 19.

Manuel, J.L., and M.J. Dadswell. 1991. Swimming behaviour of juvenile giant scallop, *Placopecten magellanicus*, in relation to size and temperature. Can. J. Zool. 69: 2250-2254.

Martin, C., J.A. Fox, and K.E. Liljestrand. 1992. Recent observations on paralytic toxins in the Atlantic deepsea scallop, *Placopecten magellanicus*, in U.S. and Canadian waters, p. 18. In J.-C. Therriault and M. Levasseur [ed.]. Proceedings of the Third Canadian Workshop on Harmful Marine Algae. Can. Tech. Rep. Fish. Aquat. Sci. 1893: 154 p.

Marshall, C.T., and K. Lee. 1991. Uptake of dissolved glycine by sea scallop (*Placopecten magellanicus* (Gmelin, 1791)) larvae, p. 60-66. In S.E. Shumway and P.A. Sandifer [ed.]. An international compendium of scallop biology and culture. World Aquaculture Workshops, No. 1. 7th International Pectinid Workshop, World Aquaculture Society.

Mayer, L.M., D.F. Schick, R.H. Findlay, and D.L. Rice. 1991. Effects of commercial dragging on sedimentary organic matter. Mar. Environ. Res. 31: 249-261.

McGladdery, S.E., R.E. Drinnan, and M.F. Stephenson. 1993. A manual of parasites, pests and diseases of Canadian Atlantic bivalves. Can. Tech. Rep. Fish. Aquat. Sci. 1931: 121 p.

Messieh, S.N., T.W. Rowell, D.L. Peer, and P.J. Cranford. 1991. The effects of trawling, dredging and ocean dumping on the eastern Canadian continental shelf seabed. Continental Shelf Res. 11: 1237-1263.

Morse, M.P., W.E. Robinson, and W.E. Wehling. 1982. Effects of sublethal concentrations of the drilling mud components attapulgite and Q-broxin on the structure and function of the gill of the scallop *Placopecten magellanicus* (Gmelin). p. 235-259. In W.B. Vernberg, A. Calabrese, F.P. Thurberg, and F.J. Vernberg [ed.]. Physiological mechanisms of marine pollutant toxicity. Academic Press, New York.

Murawski, S.A., and F.M. Serchuk. 1989. Environmental effects of offshore dredge fisheries for bivalves. Int. Counc. Explor. Sea C.M.1989/K:27, Biol. Oceanogr. Committee.

Murawski, S.A., T.R. Azarovitz, and D.J. Radosh. 1989. Long-term biological effects of hypoxic water conditions off New Jersey, USA - 1976-1989. Int. Counc. Explor. Sea Collected Papers, 1989 Council Meeting. 22 p.

Musial, C.J., and J.F. Uthe. 1983. Widespread occurrence of the pesticide toxaphene in Canadian east coast marine fish. Int. J. Environ. Analyt. Chem. 14: 117-126.

Naidu, K.S. 1970. Reproduction and breeding cycle of the giant scallop *Placopecten magellanicus* (Gmelin) in Port au Port Bay, Newfoundland. Can. J. Zool. 48: 1003-1012.

--------------- 1975. Growth and population structure of a northern shallow-water population of the giant scallop, *Placopecten magellanicus* (Gmelin). Int. Counc. Explor. Sea C.M.1975/K:37: 7 p.

--------------- 1991. Sea scallop, *Placopecten magellanicus*, p. 861-897. In S.E. Shumway [ed.]. Scallops: Biology, ecology and aquaculture. Developments in Aquaculture and Fisheries Sciences 21. Elsevier Science Publishing, B.V., Amsterdam. 1,095 p.

Naidu, K.S., and J.T. Anderson. 1984. Aspects of scallop recruitment on St. Pierre Bank in relation to oceanography and implications for resource management. Can. Atl. Fish. Sci. Adv. Comm. Res. Doc. 84/29: 9 p.

Naidu, K.S., and F. Cahill. 1986. Culturing giant scallops in Newfoundland waters. Can. Manuscr. Rep. Fish. Aquat. Sci. 1876: iv + 23 p.

Naidu, K.S., and S. Meron. 1986. Predation of scallops by American plaice and yellowtail flounder. Can. Atl. Fish. Sci. Adv. Comm. Res. Doc. 86/62: 9 p.

Parsons, G.J., S.M.C. Robinson, R.A. Chandler, L.A. Davidson, M. Lanteigne, and M.J. Dadswell. 1992. Intra-annual and long-term patterns in the reproductive cycle of giant scallops (*Placopecten magellanicus*) from Passamaquoddy Bay, New Brunswick, Canada. Mar. Ecol. Prog. Ser. 80: 203-214.

Prakash, A., J.A. Medcof, and A.D. Tennant. 1971. Paralytic shellfish poisoning in eastern Canada. Bull. Fish. Res. Board Can. 177: 87 p.

Ray, S., D.W. McLeese, L.E. Burridge, and B.A. Waiwood. 1980. Distribution of cadmium in marine biota in the vicinity of Belledune, p. 11-34. In J.F. Uthe and V. Zitko [ed.]. Cadmium contamination of Belledune Harbour, New Brunswick, Canada. Can. Tech. Rep. Fish. Aquat. Sci. 963: v + 107 p.

Ray, S., V.E. Jerome, and J.A. Thorne. 1984. Copper, zinc, cadmium, and lead in scallops (*Placopecten magellanicus*) from Chaleur Bay, New Brunswick. Int. Counc. Explor. Sea C.M.1984/E:22: 6 p.

Robinson, S.M.C., J.D. Marten, and R.A. Chandler. 1992. Assessment of a large mortality event of scallops in the Bay of Fundy. Can. Atl. Fish. Sci. Adv. Comm. Res. Doc. 92/80: 13 p.

Roddick, D.L., and R.J. Miller. 1992. Spatial and temporal overlap of the American lobster (*Homarus americanus*) and sea scallop (*Placopecten magellanicus*) as related to the impact of inshore scallop dragging. Can. J. Fish. Aquat. Sci. 49: 1486-1492.

Santoro, E.D., and T.J. Fikslin. 1987. Chemical and toxicological characteristics of sewage sludge ocean dumped in the New York Bight. Mar. Poll. Bull. 18: 394-399.

Scarratt, A.M., D.J. Scarratt, and M.G. Scarratt. 1993. Survival of live *Alexandrium tamarense* cells in mussel and scallop spat under simulated transfer conditions. J. Shellfish Res. 12: 383-388.

Seakem Oceanography Limited. 1991. Assessment of the effects of suspended dredge material on aquaculture organisms. Ocean Dumping Rep. 8, Environ. Can., Atlantic Region.

Shepard, A.N., and P.J. Auster. 1991. Incidental (non-capture) damage to scallops caused by dragging on rock and sand substrates, p. 219-223. In S.E. Shumway and P.A. Sandifer [ed.]. An international compendium of scallop biology and culture. World Aquaculture Workshops, No. 1. 7th International Pectinid Workshop, World Aquaculture Society.

Skreslet, S. [ed.]. 1985. The role of freshwater outflow in coastal marine ecosystems. Springer-Verlag, New York.

Stewart, P.L. 1994. Environmental requirements of the blue mussel (*Mytilus edulis*) in eastern Canada and its response to human impacts. Can. Tech. Rep. Fish. Aquat. Sci. 2004: x + 41 p.

Templeman, W. 1966. Marine resources of Newfoundland. Fish. Res. Board Can. Bull. 154.

Thompson, R.J. 1984. The reproductive cycle and physiological ecology of the mussel *Mytilus edulis* in a subarctic, non-estuarine environment. Mar. Biol. 79: 277-288.

Thompson, R.J., and B.A. MacDonald. 1990. The role of environmental conditions in the seasonal synthesis and utilisation of biochemical energy reserves in the giant scallop, *Placopecten magellanicus*. Can. J. Zool. 68: 750-756.

Thouzeau, G., G. Robert, and S.J. Smith. 1991a. Spatial variability in distribution and growth of juvenile and adult sea scallops *Placopecten magellanicus* (Gmelin) on eastern Georges Bank (Northwest Atlantic). Mar. Ecol. Prog. Ser. 74: 205-218.

Thouzeau, G., G. Robert, and R. Ugarte. 1991b. Faunal assemblages of benthic megainvertebrates inhabiting sea scallop grounds from eastern Georges Bank, in relation to environmental factors. Mar. Ecol. Prog. Ser. 74: 61-82.

Tremblay, M.J., and M. Sinclair. 1988. The vertical and horizontal distribution of sea scallop (*Placopecten magellanicus*) larvae in the Bay of Fundy in 1984 and 1985. J. Northw. Atl. Fish. Sci. 8: 43-53.

-- 1990. Diel vertical migration of sea scallop larvae *Placopecten magellanicus* in a shallow embayment. Mar. Ecol. Prog. Ser. 67: 19-25.

-- 1992. Planktonic sea scallop larvae (*Placopecten magellanicus*) in the Georges Bank region: Broadscale distribution in relation to physical oceanography. Can. J. Fish. Aquat. Sci. 49: 1597-1615.

Uthe, J.F., and C.L. Chou. 1987. Cadmium in sea scallop (*Placopecten magellanicus*) tissues from clean and contaminated areas. Can. J. Fish. Aquat. Sci. 44: 91-98.

Viarengo, A., and L. Canesi. 1991. Mussels as biological indicators of pollution. Aquaculture 94: 225-243.

Ward, J.E., H.K. Cassell, and B.A. MacDonald. 1992. Chemoreception in the sea scallop (*Placopecten magellanicus*) (Gmelin). I. Stimulatory effects of phytoplankton metabolites on clearance and ingestion rates. J. Exp. Mar. Biol. Ecol. 163: 235-250.

Weis, P., J.S. Weis, A. Greenberg, and T.J. Nosker. 1992. Toxicity of construction materials in the marine environment: A comparison of chromated-copper-arsenate-treated wood and recycled plastic. Arch. Environ. Contam. Toxicol. 22: 99-106.

Wildish, D.J., and D.D. Kristmanson. 1988. Growth response of giant scallops to periodicity of flow. Mar. Ecol. Prog. Ser. 42: 163-169.

Wildish, D.J., A.J. Wilson, W. Young-Lai, A.M. DeCoste, D.E. Aiken, and J.D. Martin. 1988. Biological and economic feasibility of four grow-out methods for the culture of giant scallops in the Bay of Fundy. Can. Tech. Rep. Fish. Aquat. Sci. 1658.

Wildish, D.J., and A.M. Saulnier. 1992. The effect of velocity and flow direction on the growth of juvenile and adult giant scallops. J. Exp. Mar. Biol. Ecol. 133: 133-143.

Yevich, C.A., and P.P. Yevich. 1985. Histopathological effects of cadmium and copper on the sea scallop *Placopecten magellanicus*, p. 187-198. In F.J. Vernberg, F.P. Thurberg, A. Calabrese, and W. Vernberg [ed.]. Marine pollution and physiology: Recent advances. The Belle W. Baruch Library in Marine Science, No. 13. University of South Carolina Press.

Young-Lai, W.W., and D.E. Aiken. 1986. Biology and culture of the giant scallop, *Placopecten magellanicus*: A review. Can. Tech. Rep. Fish. Aquat. Sci. 1478.