Atlas of the biology and distribution of the Sea scallop Placopecten magellanicus and Iceland scallop Chlamys islandica in the Northwest Atlantic

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1993

Canadian Technical Report of Fisheries and Aquatic Sciences No. 1915

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Cat. No. Fs 97-6/1915E ISSN 0706-6457

Correct citation for this publication:

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.

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The biology, distribution, and fisheries of the sea scallop (*Placopecten magellanicus*, Gmelin 1791) and Icelandic scallop (*Chlamys islandica*, Müller, 1776) in the Northwest Atlantic are summarized for the Northwest Atlantic Fisheries Organization Convention area (NAFO). The primary synopses are presented graphically (using maps and charts) as a visual representation of distributional patterns, and fisheries statistics. Greatest emphasis has been given to description of the sea scallop and its fishery, because of its importance within the Canadian Fisheries Conservation Zone.

Résumé

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.

L'article résume la biologie, la distribution et la pêche pour le pétoncle géant (*Placopecten magellanicus*, Gmelin 1791) et le pétoncle d'Islande (*Chlamys islandica*, Müller, 1776) à l'intérieur des zones de pêches de l'Organisation des Pêches de l'Atlantique Nord-ouest (OPANO). On a utilisé une présentation graphique par cartes et diagrammes pour illustrer les points saillants des patrons de distribution et des statistiques de pêche. On s'est attardé davantage à décrire le pétoncle géant et sa pêche étant donné son importance à l'intérieur de la Zone Canadienne de Conservation des Pêches.

Preface

The preface from the squid atlas is reproduced here in order to indicate the context within which the scallop atlas has been produced. Due to budget cuts and shifted priorities no additional atlases are planned at this stage.

Preface to the Squid Atlas

Over the years, the Biological Sciences Branch and its several predecessors have collected vast amounts of resource information in order to gain an understanding of the state of the biological resources and the factors which influence their abundance and well-being. This information exists in various forms from handwritten reports in filing cabinets, to sophisticated, but unpublished data bases, through to assorted published reports on one or another aspect. Unfortunately, not enough is available in readily understandable and comprehensive form suitable for use by the fishing industry, the general public and our own Department.

In an attempt to improve on this situation, the Biological Sciences Branch has undertaken a program to display, in graphic form, resource information presented with relevant but deliberately spare supporting text. The ultimate intention, or goal, is to make available as much as is feasible of our accumulated information through production of a series of resource atlases. To accomplish this, a position of Fisheries Analyst was created with the incumbent working with scientists within the Branch and elsewhere, to seek out and assemble the data, followed by analysis, interpretation and the choice of the most appropriate means of display.

Since conveying resource information graphically has not yet reached the status of a science, the first incumbent, Mr. G.A.P. Black, has been faced with a development task of considerable and daunting proportions. Many tools are available with many different ways of analyzing and representing the data; major adaptations and further development were required to fulfill our intentions. Additionally, although many atlases displaying resource information are extremely beautiful examples of the cartographers' craft, not all are supported by data prepared with sufficient rigour to make them reliable; viewers can be seduced by the beauty of the presentation and not be aware of or overlook the shallowness of the data. To avoid this trap, we decided at the outset that in this series of atlases, the emphasis should be placed on objectivity, quantitative representations, comprehensiveness, simplicity and reliability, as well as good looks. To this end, Mr. Black has spent much time in assembling the data and developing the computer programs for analysis, and determining the best way to present the data, as well as to store it electronically in a form which permits ready access and updating.

In the course of preparing this atlas, he has together with the co-authors illustrated very well how this system functions in presenting resource information graphically. The two atlases, one on squids and the other on scallops, bring to a close the strictly experimental phase in which the foundation for the steady production of a continuing series of resource atlases has been laid.

J.E. Stewart
Director
Biological Sciences Branch
Scotia-Fundy Region
1987

Introduction

This report is intended to provide a concise yet scientifically rigorous synopsis of the biological and fisheries information available for the scallops *Placopecten magellanicus* Gmelin, 1791 (sea scallop) (**Figure 1**) and *Chlamys islandica* Müller, 1776 (Icelandic scallop) in the Northwest Atlantic, concentrating on the Canadian fishing zone. It has been prepared for use by the fishing industry, fisheries managers and interested lay readers.

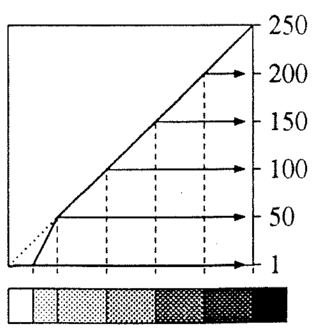
Scallops have been fished on the east coast of Canada for a long time, extending from pre-colonial times to the present. When commercial exploitation began over 100 years ago, the fishery expanded slowly to include areas of the Bay of Fundy, around Prince Edward Island, the Magdalen Islands, Gaspé, the north shore of Quebec, the Strait of Belle Isle, Scotian Shelf, and Georges Bank. The scallop fisheries have developed since then to a point where they represent a major Canadian fishery resource, ranking among the top in landed value in recent years.

Scallops have been reviewed by several authors with alternative emphasis than this report. Readers requiring additional information are referred to Bourne (1964), Mottet (1979), MacKenzie (1979) or Shumway (1991).

Data Presentation

Figures showing the spatial relationship of scallops to relevant biological and abiotic parameters are presented according to the guidelines of Bertin (1981). The maps are presented at small scale (using a Mercator projection) in *groups*, intending to convey a *graphic* representation (rather than a cartographic product) emphasizing contrasts (or similarities).

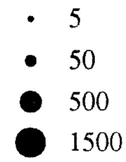
The data obtained from research surveys are represented as shaded isograms. This display mechanism is intended to convey broad scale distributional patterns. Where sampling is sparse, the shading is generated by interpolation of the surface using an inverse distance weighted gradient smoothing applied between the observed data points (Watson & Philip, 1985). The observed abundance estimates are represented as shaded regions where the grey level is proportional to the abundance estimate. The degree of linearity between the grey-level shading and the abundance estimates is shown in the legend associated with each shaded figure. As an example, the legend from Figure 5 (reproduced below) shows that the lightest grey level (associated with 1 scallop/std tow) is not linear with respect to the other grey levels (a matching linear grey level would not be detectable to the normal eye).



Example Legend from Figure 5.

On the maps showing research survey results(Figures 5, 9, 10), the edges of the area of sampling are shown by a dashed border line. This defines the area within which all sampling occurred for the given survey, and as such, any extrapolation (by the reader) of scallop abundance or variability outside these areas is hypothetical.

The data values used in developing the commercial catch figures are continuously scaled using a proportional symbol (circle) size. The scaling varies between figures to minimize overlapping (secant) circles as much as possible. *In the legend*, the numbers associated with a given circle, are the data values represented by the same sized circle.

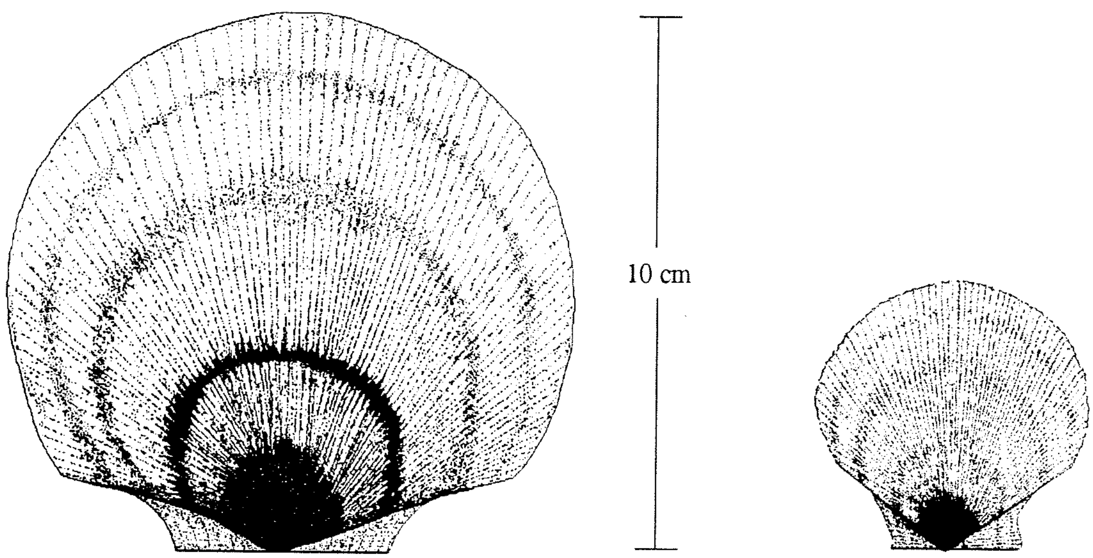


On the maps showing the commercial catches, the area of sampling is shown by an underlying grey shading. This defines the spatial area within which all reported catches occurred for the given criteria, and as such, any extrapolation (by the reader) of scallop abundance or variability outside these areas is hypothetical.

To ensure that the figures were comprehensible, much detailed information had to be aggregated. Usually this was done using more than one parameter (e.g. time and geographic area). — The reader should be aware that while these computer-generated maps are based on actual data, they present a static view of the spatial distribution rather than emphasizing the biological variability of the species over a period of time.

Classification

Phylum:	Mollusca	Cuvier, 1797		
Class:	Bivalvia	Linné, 1758		
Subclass:	Pterimorphia	Beurlen, 1944		
Order:	Ostreoida	Waller, 1978		
Suborder:	Pectinina	Waller, 1978		
SuperFamily:	Pectinidae	Rafinesque 1815		
Family:	Pectinidae	Rafinesque 1815		
Subfamily:	Chlamydinae	Korobkov, 1960		
Genus:	*Placopecten*	Verrill, 1897	*Chlamys*	Roding, 1798
Species:	*magellanicus*	(Gmelin, 1791)	*islandica*	(Müller, 1776)
Common Names:	Sea scallop, Giant scallop, Deep-sea scallop		Icelandic scallop	



Sea scallop – *Placopecten magellanicus*   Icelandic scallop – *Chlamys islandica*

Figure 1. General representation of the dorsal view of *Placopecten magellanicus* and *Chlamys islandica* as adults (adapted from Bourne, 1964). Note that while the scale is approximate, *Placopecten magellanicus* are larger as adults.

Biology

This biological overview describes both sea and Icelandic scallops. In general, sea scallops are presented first, followed by a description of Icelandic scallops. If scallops are mentioned and the species is not identified, it may be assumed that the term applies to both species.

Anatomy

As illustrated in Figure 1, Sea scallops are much larger than Icelandic scallops. The former will attain a shell height of 21 cm (Mottet 1979, see ref. to Norton 1931) while Icelandic scallops rarely exceed 10 cm (Vahl, 1981). The Icelandic scallops usually have smaller adductor muscles (meats) compared to sea scallops. The smaller meat production, combined with their slow growth rate, makes them a less desirable species for exploitation.

The external anatomy of these scallops is a shell comprised of two valves that are relatively round with shallow curvature similar to opposing saucers (**Figure 2**). In its normal orientation on the sea floor the right valve is on the bottom. In the sea scallop, the right valve is flatter and generally lighter in colour than the left (top) valve. The two valves are joined by a hinge. The shell height measurement, is the maximum distance between the hinge and the ventral margin. The slight flarings of the shell at the hinge are known as wings or ears. The smaller wing of the right valve has a byssal notch through which in younger animals especially, byssal threads exit and form an attachment to the substrate. The shells often display concentric rings associated with either annual events or trauma. The annual rings are used for aging the animals (Merrill et al., 1966).

The internal anatomy (**Figure 3**) contains the soft tissues and represents about 40% (Bourne, 1964) of the animal's weight. In North America the major commercial portion of the animal is the adductor muscle (meat), which pulls the shells closed and weighs about a third of the total soft tissues or about 13% of the total animal's weight. The adductor muscle is composed of two sections. The larger part is called the quick muscle and it is used for rapid contractions of the shells. The smaller tougher muscle, known as the catch muscle, is used to hold the shell in a given position. The gonad of a scallop is crescent shaped and curves around the adductor muscle. In mature animals the male gonads are creamy white and the female's gonads orange to coral red. Although common in some bivalves, hermaphrodites are rare in sea scallops. The soft tissues of the scallop are enclosed, for protection in a membrane known as the mantle; it also secretes the shell. When scallops are resting, their numerous tentacles and eyes are clearly visible around the periphery of the gaping valves. The many other organs and systems which scallops contain have been described in detail by Bourne (1964) and Mottet (1979).

Life History Synopsis

The major spawning period for sea scallops is the late summer-fall (August to October), with any one population generally spawning over a period of 2 weeks to a month. Two spawnings, spring and fall, have been reported for coastal Newfoundland (Naidu, 1970), New Hampshire (Savage, 1980), and mid-Atlantic Bight (DuPaul et al., 1989; Schmitzer et al., 1991). Spring spawning could possibly contribute significantly to recruitment of commercial beds on Georges Bank (C. DiBacco, 1991). The exact timing varies from area to area and year to year.

The fertilized eggs develop into planktonic larvae, which metamorphose and settle to the bottom within 30 to 60 days, depending on ambient temperatures.

Icelandic scallops also spawn once annually (Vahl, 1981). They grow more slowly, and to a smaller asymptotic size than sea scallops. In all other respects their basic life history is similar to that of sea scallops.

Distribution

Sea scallops are found only in the northwest Atlantic Ocean. Posgay (1957) gives a southern limit of Cape Hatteras, while Squires (1962) showed the northern limit was the northern tip of Newfoundland. The animals are aggregated in patches and the discrete harvestable concentrations are

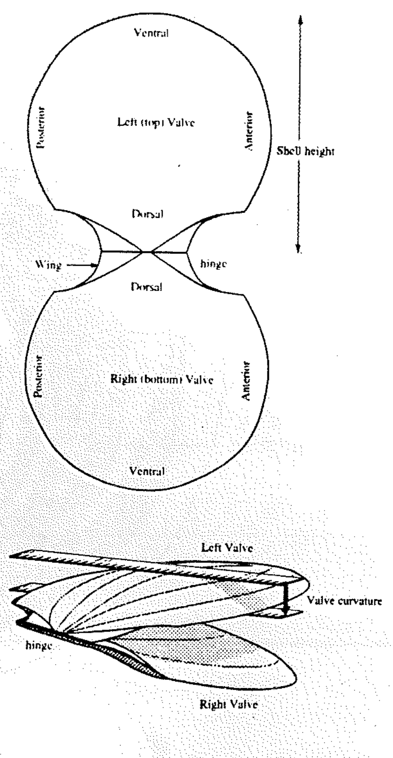


Figure 2. Anatomical features and orientation of the sea scallop *Placopecten magellanicus*.

known as beds. **Figures 4** and **6** show the major areas of fishing activity. The size of scallop beds are determined in general by the success of spawning and settlement (recruitment) and by the fishing effort directed toward the individual scallop beds. The variability in population size and discreteness is discernible for each fishable cohort (year class) observed in the research surveys conducted on Georges Bank (**Figure 5**).

Icelandic scallops are a circumpolar species (Mottet, 1979) and are usually found in waters as far north as Spitsbergen and have been observed as far south as Cape Cod (Serchuk & Wigley, 1984). Fishing for Icelandic scallops in Canadian waters is concentrated on St. Pierre Bank, the northern shore of the Gulf of St. Lawrence, the Strait of Belle Isle, and the Labrador coast (**Figure 6**).

Interactions with Other Species

Species which the scallops prey upon since they are filter feeders consist of diatoms, protozoans, detritus, and associated bacteria (Mottet, 1979; Shumway et al., 1987). As well as predator-prey interactions, post-larval and juvenile red hake (*Urophysis chuss*) use them as refuges by inhabiting the mantle cavity of sea scallops (Wigley and Theroux, 1971). The relationship is commensal and the well being of the scallop is not compromised by the fish.

Icelandic scallops have been found in the stomachs of American plaice (*Hippoglossoides platessoides*) and Yellowtail flounder (*Limanda ferruginea*) (Naidu & Meron, 1986). Similarly, sea scallops are predated upon by flatfish and large decapod crustaceans (Elner & Jamieson, 1979).

Growth

The position of external rings on the shell is the most frequently used age indicator. The annual rings are formed by a relative slowing of growth rate when water temperatures drop in the late winter. Rings are also formed by trauma, such as the impact of a fishing dredge or disturbance from storms. MacDonald (1984) found that at times, "shock" rings could easily be confused with annual rings and the age overestimated. Further, MacDonald also found that the annual marks on the ligament were better indicators than the external rings. Length frequency analysis, tagging studies, and oxygen-isotope ratio analysis provide other means for estimating growth.

Adult growth, in terms of shell height, has been estimated for most of the major commercial beds (**Table 1, Figure 7**). Georges Bank and beds in Port au Port Bay off the west coast of Newfoundland are seen to have the fastest growth rate for sea scallops. Adult growth, reflected by changes in meat weight (weight of the adductor muscles)

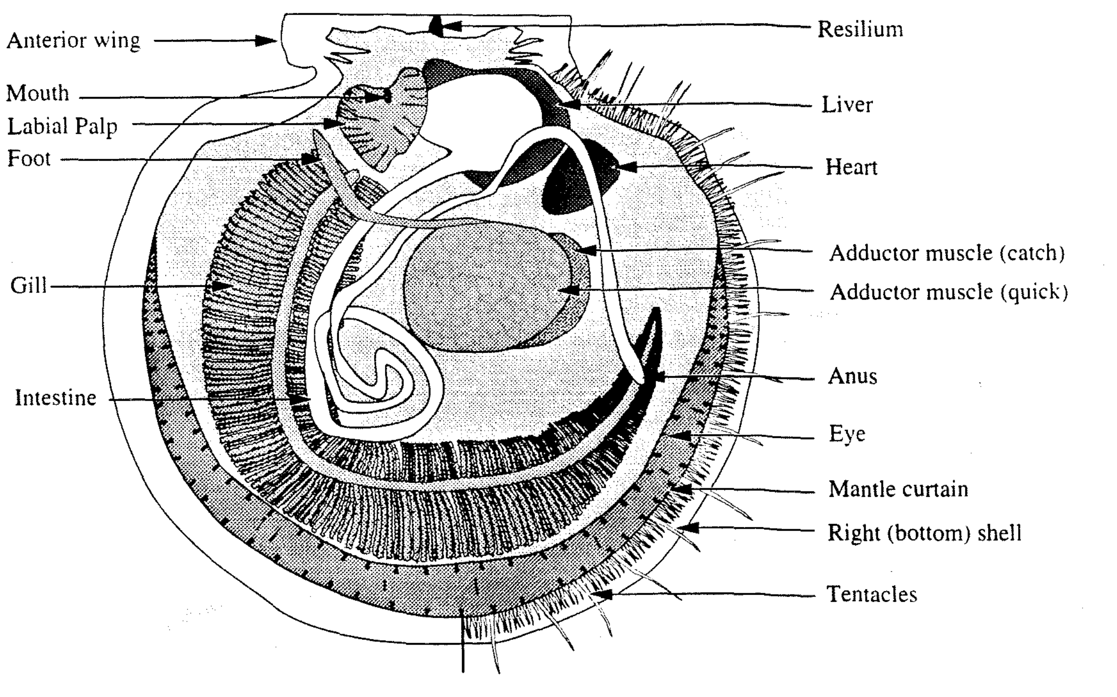


Figure 3. Internal anatomy of the sea scallop *Placopecten magellanicus* (after Mottet,1979 and Bourne, 1964).

is highly variable. The rate changes from area to area but is also a function of season, depth, and temperature. Gametogenesis, and probably to a lesser degree temperature and food availability, are responsible for a seasonal component in somatic growth (MacDonald & Thompson, 1986; Robinson et al. 1981).

Icelandic scallops grow more slowly and have a smaller asymptotic size compared to sea scallops (**Figure 7**). Vahl (1981) presents size at age data, which shows 8 year old animals having a mean shell height of 65 mm and 16 year old animals a height of 80 mm. Observations from Naidu et al. (1982) for St. Pierre Bank, the Strait of Belle Isle, and the northeastern Gulf of St. Lawrence, show reduced growth rates, and a lower asymptotic size. Similar studies by Pedersen (1989) show a slow growth rate for scallop beds in western Greenland.

Reproduction

In sea scallops, gonadal growth and maturation generally take place between April and July; spawning occurs from August to October (Thompson, 1977). Instances of two separate spawnings, spring and fall, have been reported (Naidu, 1970). Most animals are sexually mature by their second year. The reproductive effort (annual gamete production divided by gamete and somatic tissue production) increases steadily from about 20% at age 2 to nearly 100% around age 14 in inshore scallops (MacDonald, 1984). Annual egg production per animal is numbered in the tens of millions and higher. Egg diameter has been reported at 80–90 µm (Naidu, 1970) and 69 µm by MacDonald (1984).

Icelandic scallops mature at a later age and devote less energy to reproduction than sea scallops. Vahl (1981) reported for Norwegian waters that 50% maturity was attained at about age 4. He also estimated the reproductive effort (using a slightly different definition than above, the ratio of gamete production to total production) to increase from 2% at age 4 to 75% for ages 15-20.

Early Life Stages

The general life cycle of scallops is shown in **Figure 8**. The following description of the early development of sea scallop larvae is based on laboratory studies at temperatures of 13 to 15°C (Culliney, 1974; Couturier, 1990). After 1 to 2 days as negatively buoyant eggs, the first motile stage is reached, that of the ciliated trochophore. Within 3-4 days of fertilization, the larvae develop into the veliger stage, which is characterized by the velum - a bilobed ciliated organ used in locomotion and feeding. The early veliger has a hinged, 'D' shaped shell (prodissoconch I) which is deposited by the shell gland. When the larvae initiate feeding at about 4 days, new shell (prodissoconch II) be-

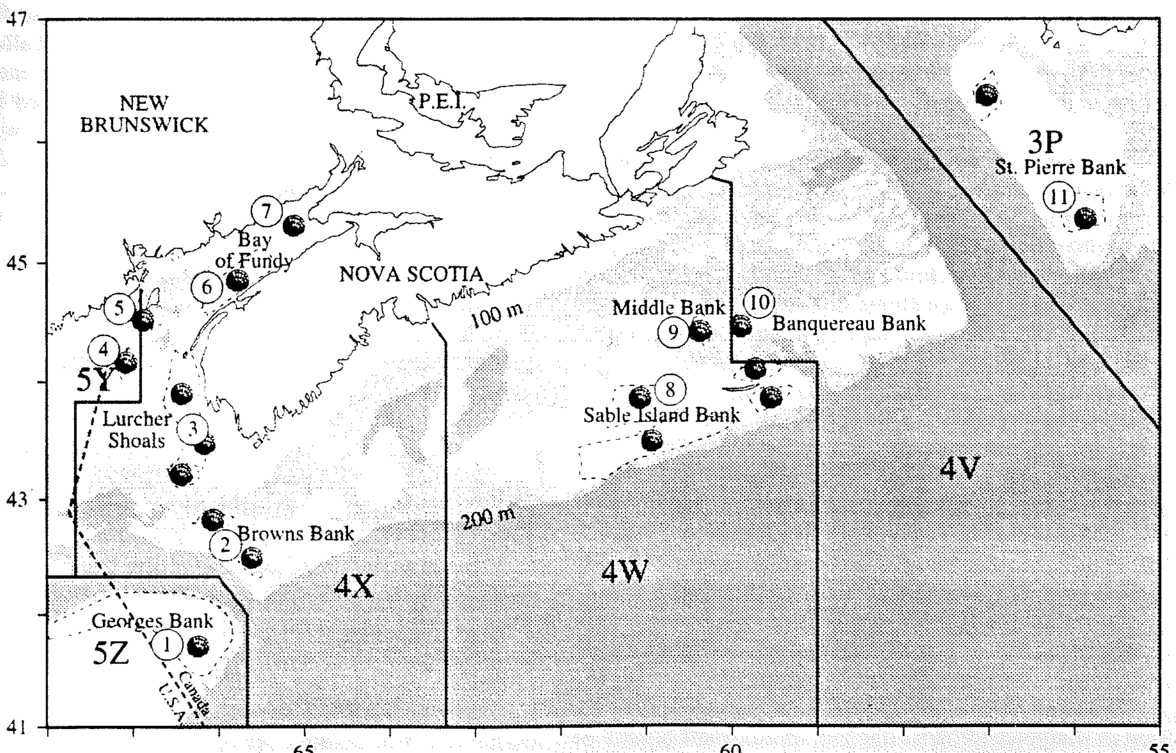


Figure 4. Major areas of fishing activity for sea scallop *Placopecten magellanicus* on the Scotian Shelf, and Georges Bank: 1 - Georges Bank, 2 - Browns Bank, 3 - Lurcher Shoals, 4 - Southwest Bank, 5 - Grand Manan, 6 - Digby, 7 - Upper Bay of Fundy , 8 - Sable Island Bank, 9 - Middle Bank, 10 - Banquereau Bank, 11 - St. Pierre Bank.

gins to be added peripherally in concentric growth lines. Changes occurring during the veliger stage include shell shape, the development of a light sensitive eye spot, and the acquisition of a foot. Larvae with a foot (pediveligers) tend to spend more time on or near the bottom than do earlier stages. Settlement on the bottom and metamorphosis are thought to occur almost simultaneously as metamorphosis involves a rapid degeneration of the velum. Metamorphosis occurs at lengths of 230 to 280 μm, which can be reached in 30-35 days in the laboratory.

In nature, sea scallop larvae have only rarely been studied, probably because of the perception that they are difficult to identify. Distinguishing sea scallop larvae from other species of scallops may indeed be difficult, but this is generally not a problem in the Gulf of Maine area since sea scallops are much more abundant and fecund than other species, and probably spawn later in the year (Tremblay et al., 1987; Tremblay & Sinclair, 1988).

In the Bay of Fundy, sea scallop larvae are most abundant during September, with declining numbers thereafter in 1984 (**Figure 9**). On Georges Bank larvae reach a seasonal peak in late September or early October, and show dramatic shifts in distribution over periods of a few weeks in 1986 and 1987 (**Figure 10**). Sea scallop larvae are most abundant on Georges Bank, followed by the Bay of Fundy and Browns Bank (Tremblay &Sinclair 1988, 1992).

The vertical distribution of sea scallop larvae is strongly related to the physical characteristics of the water column. In areas where waters are well-mixed, with little density stratification (as shown by Sigma-t[1]), sea scallop larvae are evenly distributed over the entire water column. In areas where there is density stratification, larvae show subsurface aggregations, which tend to be associated with the area where the vertical density gradient is greatest (pycnocline) (**Figure 11**) (Tremblay & Sinclair, 1990a). Sea scallop larvae undertake a small vertical migration in some areas, occupying shallower depths at night (Tremblay & Sinclair, 1990b).

Post-larval stages

Although young sea scallops have been found associated with bryozoans in Penobscot Bay (Maine) (Baird, 1953; Caddy, 1972), little is known about this life stage. Juvenile scallop abundance on Georges Bank is not related to easily quantified physical factors such as sediment size, depth, temperature and salinity (Larsen & Lee, 1978). New evidence suggests that 1-2 year old animals are more abundant in the gravel-pebble deposit in the northern half of the Bank (Thouzeau et al., 1991). In the laboratory, juveniles 2-5 mm in diameter remain attached approximately 75% of the time; this proportion decreases with increasing age (Caddy, 1972).

Following metamorphosis and settlement, the growth rate increases dramatically over that of the larval stages. Sixty-day old spat reared in the laboratory can be as large as 1 mm (mean growth rate of 25 μm per day) while 160-day old spat can be as large as 1 cm (mean growth rate of 75 μm per day) (P. Dabinett, pers. comm.) In Passamaquoddy Bay (New Brunswick), spat which have settled in the autumn can reach a size of 2 mm by November, and 5 mm 50 days later — a growth rate of 60 μm per day (M. Dadswell & Parsons, 1991). In contrast, on Georges Bank, reported post-larval growth rates are substantially lower. Scallops of approximately 6 months old, were found to have a mean size of 2.9 mm by Merrill and Edwards (1976), and only 1.3 mm by Larsen and Lee (1978).

Physiology

Scallops have large gills which carry out both respiratory and feeding functions. MacDonald (1984) reports oxygen consumption and clearance rates (the volume of water filtered during feeding) for sea scallops. Both these rates are seasonal and correlated with temperature and food availability. For scallops in the size range of 135 to 155 mm, mean O_2 consumption ranged from approximately 1 to 3.5 ml/h. The clearance rate ranged from 4 to 9 l/h. Van Dam (1954) reports an O_2 uptake of 70 ml/kg/hr at 20°C.

Scallops display the rather unusual behaviour, for bivalves, of swimming. The tendency to swim is more common among younger animals and rarely seen in scallops over 70 mm. The respiration rate for sea scallops is higher than that of more sedentary bivalves. The energy requirements of swimming have not been reported in the literature. Among 4 species tested, sea scallops were the most hydrodynamically suited for swimming (Dadswell & Weihs, 1990). Scallops approach optimum hydrofoil shape for low aspect body ratio. Dadswell and Weihs (1990) determined that mean flight distances were 2.6 ± 0.6 m (with a range of 1.0 - 7.0 m) and mean velocity of 47.6 cm/s (with a range of 4 - 9 body lengths/s). Melvin et al. (1985) report a mean movement of a few kilometers per year from the analysis of tag-recapture data on Georges Bank. The average motion observed was circular in a clockwise direction, which corresponds to the residual surface currents.

Vahl (1981) reports a respiration rate for Icelandic scallops in units different from MacDonald (1984). Respiration effort would range from twice for young animals to a factor of 4.5 for older animals of the energy allotted to total production.

Meat Quality

Normal scallop meats are creamy-white in colour and have a firm texture. At times, some dark-meated scallops are encountered; they are greyish brown in colour, flaccid, and stringy in texture. Meat yield from these scallops is

[1] Sigma-t – The specific gravity of water of temperature *t*°, usually expressed in terms of (specific gravity at *t*°C-1) × 1000.

also usually smaller. Dark-meated scallops are infected to varying degrees by a boring sponge that slowly destroys the shells of many species of molluscs (Medcof, 1949). In scallops, the disease is revealed by a fine pitting of the surface, which gradually spreads to the whole shell. Meanwhile, the scallop deposits more shell layers from the inside but is not always successful at keeping pace with the invader. The meat condition deteriorates when the animal spends too much energy repairing its shell, especially in older animals.

Fishery

History

Scallops have been utilized on the east coast of Canada for a considerable period. Scallop shells from Indian middens were found as evidence of exploitation before colonization (Bourne, 1964). Scallops were caught in 1605 at Port Royal, in the Annapolis Basin, Nova Scotia:

> "There are also there, scallops (Palourdes), twice as large as oysters in size; also cockles, which have never failed us." (Lescarbot, 1609).

In addition scallops have been exploited commercially in eastern Canadian waters for at least 100 years. Willis (1862) reported that scallops were sold in Halifax for as high as a shilling apiece, and scallops caught in Mahone Bay were consumed regularly in Lunenburg. A more important fishery developed in the Bay of Fundy:

> "In New Brunswick a schooner occasionally brings a quantity (of scallops) to St. John from L'Etang Harbour or Maces's Bay where they are taken by dredges...the quantity sold is estimated to be about 200 bushels annually." (Ganong, 1889)

On the Nova Scotia side of the Bay, the scallop fisheries remained relatively quiescent until the discovery of scallop beds in the Annapolis Basin in 1920. The fishery commenced there and expanded into the Bay of Fundy. Fishermen soon began to shuck the catch at sea, which improved the handling of the catch considerably.

Other fisheries for scallops developed in the Gulf of St. Lawrence, around Prince Edward Island, Magdalen Islands, Gaspé, the north shore of Quebec, and the Strait of Belle Isle; their importance was local and the stock abundance did not always sustain a fishery for long.

An offshore scallop fleet developed and extended its range to include Georges Bank in 1945. Growth of this fishery was slow until 1954, when the success of larger more powerful boats stimulated further activity. Scallop beds on St. Pierre Bank, on the Scotian Shelf from Middle Ground to Lurcher Shoals were also discovered. The offshore fishery now accounts for a significant portion of the Canadian scallop catches (for example, approximately 80% in 1985, and 60% in 1988).

The gear used, called drags, rakes, or dredges, now consists of a heavy metal frame and a steel bag(s) to contain the scallops, made with steel rings joined with steel split links or rubber washers in the case of inshore drags. The offshore drags are 4-4.6 m in width, while the inshore gear may be 2.5 m wide and is considerably lighter.

Trends

Scallop catches from the inshore fleet ranged from 225-775 tonnes of meats before the offshore fishery began in 1945. Inshore landings of the Digby scallop fleet from 1930-1952 were correlated with water temperatures recorded 6 years earlier (lagged), indicating a temperature effect on recruitment during the early life history of the scallop (Dickie, 1955). Inshore landings of the Digby fleet for 1922-1972 showed evidence of a 9-year oscillation in recruitment in addition to an overall decline in catches since the 1930's (Caddy, 1979). Water temperature showed a lagged correlation with catch (warmer water in a given year during the spawning and the planktonic larval periods appeared to be related to higher catches up to 6 years later). This may be attributable to some improvement in spawning success or larval settlement during periods of warmer water. Long-period tidal oscillations may be responsible for fluctuations in both temperature and recruitment. More recent data suggests a recruitment period of about 20 years for both the Bay of Fundy inshore landings and for the offshore landings from Georges Bank. **Figure 12** shows the Georges Bank landings and a superimposed 18 year sine wave. The amplitude and phase of the wave were determined by Fourier analysis. This periodicity is similar to an 18.6-year tidal period that is seen in the Gulf of Maine (Loder, 1980). The influence of the 18.6-year tidal period has been reported for several fish and invertebrate species in the Bay of Fundy, Gulf of Maine area in Cabilio et al. (1988). In the Bay of Fundy, landings in statistical districts 37-39, 48-53 (**Figure 13**) display a more complicated pattern when fitted using a time series. In **Figure 14,** a periodic cycle composed of two sine waves, which were the dominant wave forms in the catch spectrum, having periods of 8.9 and 20.7 years, is superimposed with inshore catches. Peak offshore catches occurred during the early 1960's and late 1970's (15,440 and 16,456 tonnes) with average catches of 7,000-10,000 tonnes of meats.

Catches

The scallop catches for Georges Bank, Northwest Atlantic Fisheries Organization (NAFO) Subdivision 5Ze are given in **Table 2**, and shown in **Figure 12.** The commercial catches for Canada (as total catch per 10 minute square, TMS) from Georges Bank for the period 1957-

1984 are given in **Figure 15**. The distribution of U.S.A. commercial catches for the period 1957-1980 are shown in **Figure 16**. Catches from scallop beds on the Scotian Shelf and St. Pierre Bank are presented in **Table 3**. Catches for the long standing fishery in the Bay of Fundy are presented in **Table 4** from 1967 onward. The catches for the Gulf of St. Lawrence, Gaspé, and Magdalen Islands are given in **Table 5**. The Georges Bank catches are by far the most important.

The landings of *Chlamys islandica* in the strait of Belle Isle, in the northeastern Gulf of St. Lawrence are given in **Table 6**. There was a dramatic decrease in catches in 1974 attributed to heavy ice conditions, the success of fishing for other species, and reduced market value for scallops. As a result, no fishing activity occurred during the years 1975 through 1978.

Fisheries Management

Scallops are a very valuable resource fetching high prices at the point of landing. The value of the fishery has ranked among the top during the past 10 years. In 1987 the value (in millions of $) of the top four species in the Atlantic zone were: $328 (Cod), $264 (Lobster), $112 (Scallop), $78 (Crab). In 1988 the value (in millions of $) of the top four species were: $238 (Cod), $250 (Lobster), $99 (Crab), and $84 (Scallop). The main objective in the management of this fishery has been to conserve the resource to provide increased benefits to the Canadian fishing industry. Long-term goals advocate a harvesting strategy that promotes increased landings and a certain degree of stability.

Fishery management for scallops began in 1918 with the introduction of a $1 fee, a closed season (June 1 to Sept. 15) and a size restriction (100 mm minimum shell height) on scallops in Mahone Bay and Chester Basin, Nova Scotia (Anonymous, 1920). Measures have evolved since then with the meat count (restriction on the size of meats that may be shucked), and an enterprise allocation regime (allocation of the allowable catch amongst the participating fishing companies), being the main management tools pertaining to offshore areas. In inshore areas such as the Bay of Fundy waters and the Northumberland Strait in the southwestern Gulf of St. Lawrence, access to the most productive grounds is restricted seasonally. Other measures such as limited entry, width of gear, ring size, also apply depending on the area. In a limited entry fishery, the number of vessels permitted to fish is controlled. Regulations which specify the maximum width of the drags, effectively reduce the area of scallop bed which may be fished over a given time period. Regulations establishing an appropriate minimum ring size for the rings forming the scallop dredge bag, alter the selectivity of the gear somewhat to catch fewer younger (smaller) scallops. Sinclair et al. (1985) have compiled a chronological summary of the different regulations dealing with the exploitation of scallop resources. Current regulations are published in the Canadian Gazette.

Utilization

In contrast to intertidal clams, scallops normally live completely submerged, without exposure to the air. Evolving within this ecological niche, the anatomy of the scallop does not permit the complete closing of the valves. When harvested, the soft tissue is exposed to the air so that the maximum survival time is about 40 hours (Hirasawa, 1972 from Mottet, 1979). In Japan and western Europe, local markets exist for whole scallops (Mottet, 1979). While all the soft tissue of some scallop species is edible, the presence of Paralytic Shellfish Poisoning (PSP) in some fishing areas limits the utilization of the whole animal. Traditionally, only the adductor muscle (meat) is retained for market in Canada. At times there has also been attempts at using gonadal materials. In recent years, the offshore fleet has conducted a small-scale roe fishery. Scallop meats shucked at sea, packed in cotton bags, and stored on ice, were kept as long as 15 days (Bourne, 1964). Nowadays, quality awareness has considerably reduced the length of fishing trips. Frozen and breaded scallops are common products, with fresh meats commonly used by the restaurant trade.

Future Prospects

Offshore stocks have experienced good recruitment lately and effort has somewhat been reduced so that catch-rates have stabilised or increased slightly. The Scotian Shelf stocks have a relatively short history, and their catch levels here are very much dependent on the performance of the Georges Bank stocks in a somewhat inverse relationship.

Future catch levels of the inshore stocks in the Bay of Fundy depend strongly on reducing fishing capacity/effort.

Acknowledgments

The data used to generate the maps and diagrams were obtained from a variety of government and industry sources. Scallop research surveys contributed much of the data. The value of the considerable efforts by the many scientists and personnel who planned and conducted these surveys is greatly appreciated; we thank all those who participated. We also thank J. E. Stewart for critically reviewing drafts of the manuscript.

Table 1. Von Bertalanffy Growth equation parameters: $Height_t = Height_\infty \left(1 - e^{-k(t - t_0)} \right)$

Area	$Height_\infty$ mm	k	t_0 years	Source
Placopecten magellanicus				
Georges Bank	152.46	0.3374	1.454	Serchuk et al, 1979
Newfoundland	152.0	0.29	0.55	Naidu, 1975
Georges Bank	145.4	0.38	1.5	Brown et al, 1972
Bay of Fundy	143.21	0.2221	1.38	Robert et al, 1989a
Sable Island	136.71	0.2264	1.335	Robert et al, 1989b
Northumberland Strait	108.83	0.3259	0.464	Chouinard, 1984
Chlamys islandica				
St. Pierre Bank	109.9	0.1817	0.380	Naidu et al, 1982
Strait of Belle Isle	107.3	0.149	0.888	Naidu et al, 1982
Greenland	97.0	0.12	1.35	Pedersen, 1989

$Height_\infty$ – controls the asymptotic maximum height.
k – controls the rate of curvature of the equation.
t_0 – controls the age at which the height is 0.

Table 2. Catch statistics (tonnes of meats) for Georges Bank (NAFO Subdivision 5Ze and 5Zw not separated prior to 1967). Source: Sinclair et al., (1985); Mohn et al., (1989). *See also* **Figure11**.

Year	U.S.A.	Canada	Total	Year	U.S.A.	Canada	Total
1953	7392	148	7540	1971	1334	3908	5242
1954	7029	103	7132	1972	824	4161	4985
1955	8299	120	8419	1973	1084	4223	5307
1956	7937	318	8255	1974	929	6137	7066
1957	7846	766	8612	1975	860	7414	8274
1958	6531	1179	7710	1976	1777	9675	11452
1959	8910	1950	10860	1977	4823	13089	17912
1960	10039	3402	13441	1978	5589	12189	17778
1961	10698	4565	15263	1979	6412	9207	15619
1962	9725	5715	15440	1980	5477	5221	10698
1963	7938	5898	13836	1981	8443	8013	16456
1964	6322	5922	12244	1982	6523	4307	10830
1965	1515	4434	5949	1983	4328	2748	7076
1966	905	4878	5783	1984	3071	1945	5016
1967	1234	5011	6245	1985	2949	3812	6761
1968	998	4820	5818	1986	4438	4670	9110
1969	1329	4318	5647	1987	8800	6793	15593
1970	1420	4097	5517	1988	6100	4336	10436

Table 3. Catch statistics (tonnes of meats) for St. Pierre Bank, the eastern Scotian Shelf (Middle Ground, Sable Island area: NAFO Subdivision 4W) and the western Scotian Shelf (Browns, German Bank, and Lurcher Shoals: NAFO subdivision 4X). (Source: Statistics Division, Fisheries & Oceans, P.O. Box 550, Halifax, N.S. B3J 2S7; NAFO Statistical Bulletins for St. Pierre Bank, Northwest Atlantic Fisheries Organization, P.O. Box 638, Darthmouth, N.S. B3Y 3Y9).

Year	St. Pierre Bank	Eastern Shelf	Western Shelf	Total
1967	159	1	162	322
1968	14	-	91	105
1969	93	101	114	308
1970	150	95	15	260
1971	33	16	20	69
1972	29	-	5	34
1973	36	13	2	51
1974	-	-	-	-
1975	-	-	-	-
1976	-	33	751	784
1977	-	-	102	102
1978	14	-	27	41
1979	17	-	683	700
1980	31	68	1704	1803
1981	-	1	631	632
1982	720	137	937	1794
1983	578	296	737	1611
1984	413	86	246	745
1985	53	93	52	198
1986	153	685	76	914
1987	85	422	1	508
1988	987	101	7	1095

Table 4. Catch statistics (tonnes of meats) for the Bay of Fundy and approaches (NAFO subdivision 4Xr and 4Xs) for the Bay of Fundy fleet mainly represented by vessels 14-19.8m L.O.A. and the mid-Bay fleet by vessels under 14m. (Source: Statistics Division, Fisheries & Oceans, Halifax.)

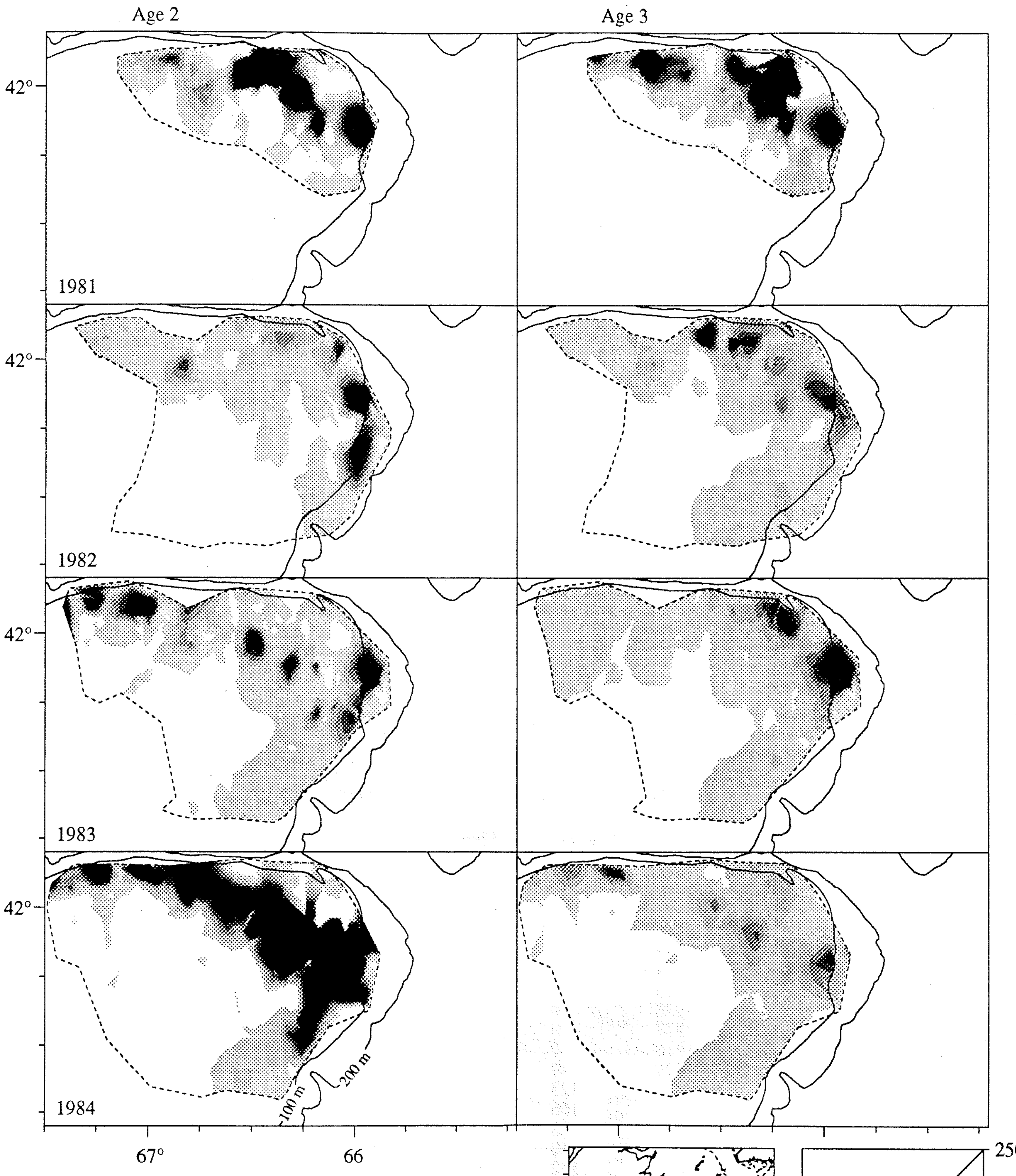
Year	Mid-Bay Fleet	Bay of Fundy Fleet	Total	Year	Mid-Bay Fleet	Bay of Fundy Fleet	Total
1967	43	127	170	1978	40	490	530
1968	87	377	464	1979	60	405	465
1969	50	281	311	1980	188	739	927
1970	41	245	286	1981	494	954	1448
1971	29	173	202	1982	289	1022	1311
1972	41	237	278	1983	191	823	1014
1973	27	134	161	1984	190	639	829
1974	17	58	75	1985	213	508	721
1975	-	103	103	1986	175	191	366
1976	30	238	298	1987	208	143	351
1977	-	464	464	1988	325	768	1093

Table 5. Catch statistics (tonnes of meats) for the Gulf of St. Lawrence (NAFO Subdivision 4T and 4S. (Source: Giguère et Légaré (1989a;b) and Lanteigne et Davidson (1988)).

Year	North Shore	Gaspé	Magdalen Islands	Southern Gulf	Total	Year	North Shore	Gaspé	Magdalen Islands	Southern Gulf	Total
1954	3	-	-	-	3	1972	18	25	86	506	635
1955	-	-	-	-	-	1973	4	29	49	304	386
1956	22	-	-	-	22	1974	7	19	35	201	262
1957	<1	-	-	-	<1	1975	58	21	43	276	398
1958	2	-	-	-	2	1976	67	45	36	362	510
1959	3	-	-	-	3	1977	12	17	26	193	248
1960	15	-	-	-	15	1978	21	20	48	267	356
1961	-	-	-	-	-	1979	28	18	44	230	320
1962	-	-	-	-	-	1980	25	17	62	201	305
1963	-	-	-	-	-	1981	24	13	53	357	447
1964	-	-	-	-	-	1982	5	9	22	268	304
1965	-	-	184	-	184	1983	14	11	65	334	424
1966	-	-	46	-	46	1984	45	20	68	257	390
1967	-	-	57	902	959	1985	76	15	66	257	414
1968	33	-	158	896	1087	1986	116	14	28	265	423
1969	49	39	357	639	1084	1987	215	13	19	207	454
1970	69	86	343	694	1192	1988	130	14	21	n/a	165
1971	40	35	124	588	687						

Table 6. Catch statistics (tonnes of meats) for Iceland scallops from the northeastern Gulf of St. Lawrence (NAFO Subdivision 4R). (Source: Lanteigne et Davidson (1988)).

Year	N.E. Gulf	Total
1969	27	27
1970	21	21
1971	18	18
1972	281	281
1973	237	237
1974	26	26
1975	0	0
1976	0	0
1977	0	0
1978	0	0
1979	49	49
1980	123	123
1981	166	166
1982	38	38
1983	40	40
1984	152	152
1985	274	274
1986	214	214
1987	60	60



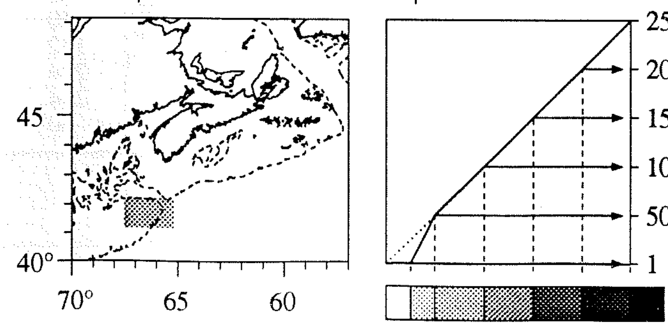


Figure 5. The abundance of age 2 and 3 sea scallops *Placopecten magellanicus* on Georges Bank between 1981-1984. The abundance is calculated as the number of scallops / std tow, and is represented proportionally as a shaded surface. The cohorts may be "read" diagonally by comparing one plot of a particular age with the succeeding plot for the next year (in the next age group). The dashed border line defines the area within which all sampling occurred for the survey.

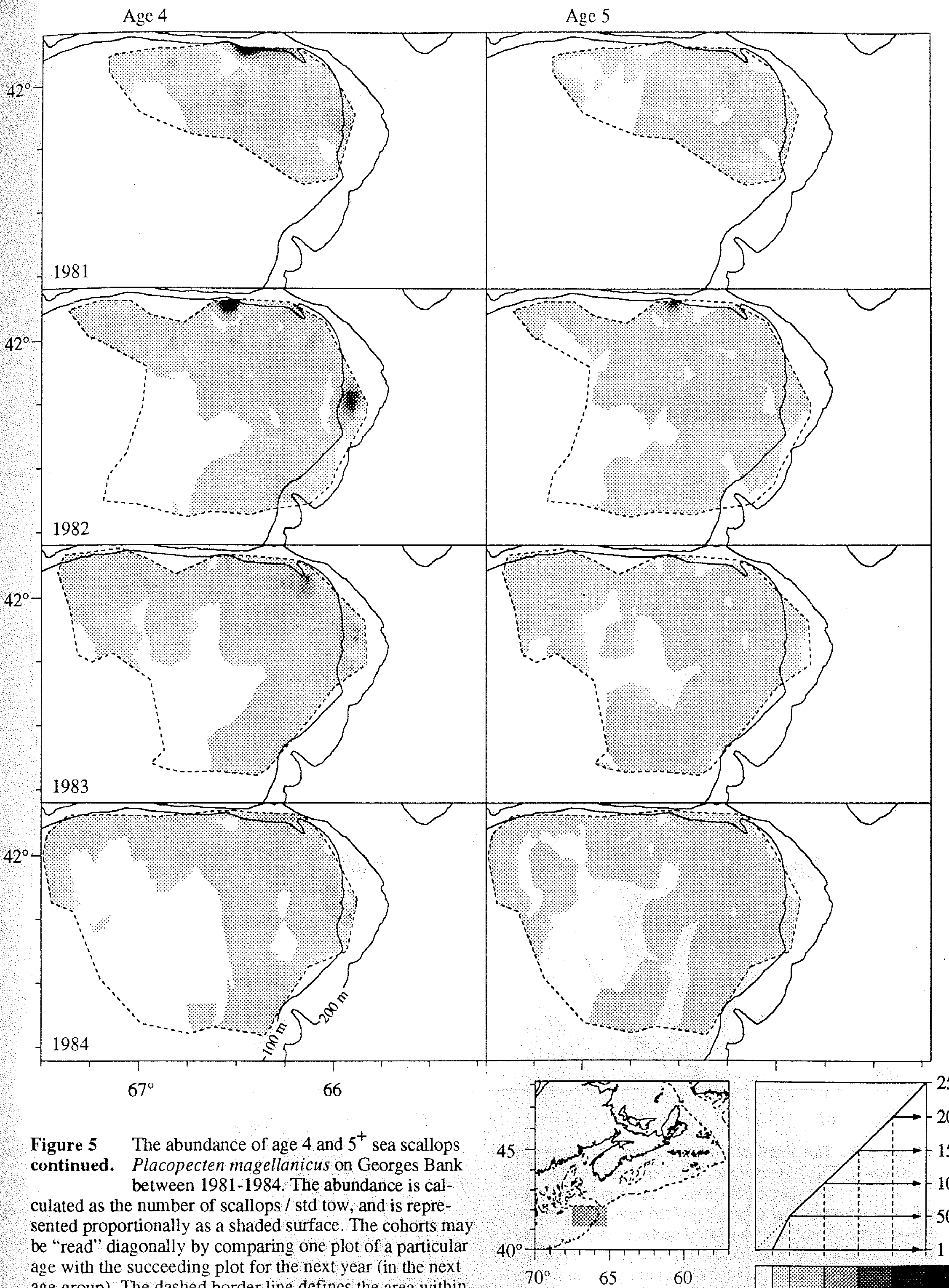
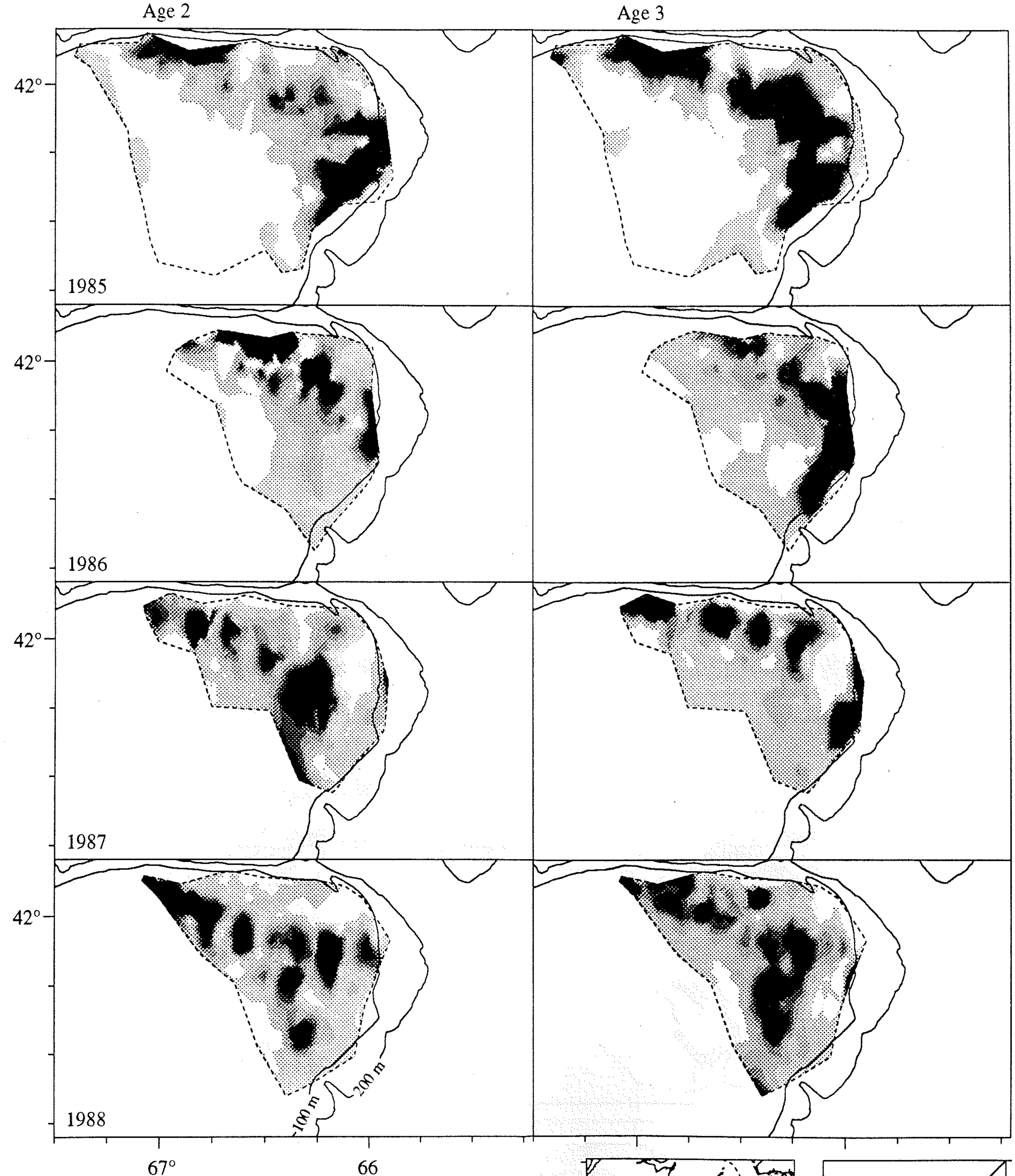


Figure 5 continued. The abundance of age 4 and 5^+ sea scallops *Placopecten magellanicus* on Georges Bank between 1981-1984. The abundance is calculated as the number of scallops / std tow, and is represented proportionally as a shaded surface. The cohorts may be "read" diagonally by comparing one plot of a particular age with the succeeding plot for the next year (in the next age group). The dashed border line defines the area within which all sampling occurred for the survey.



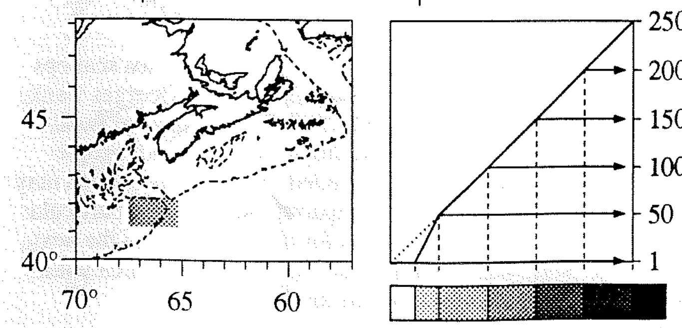
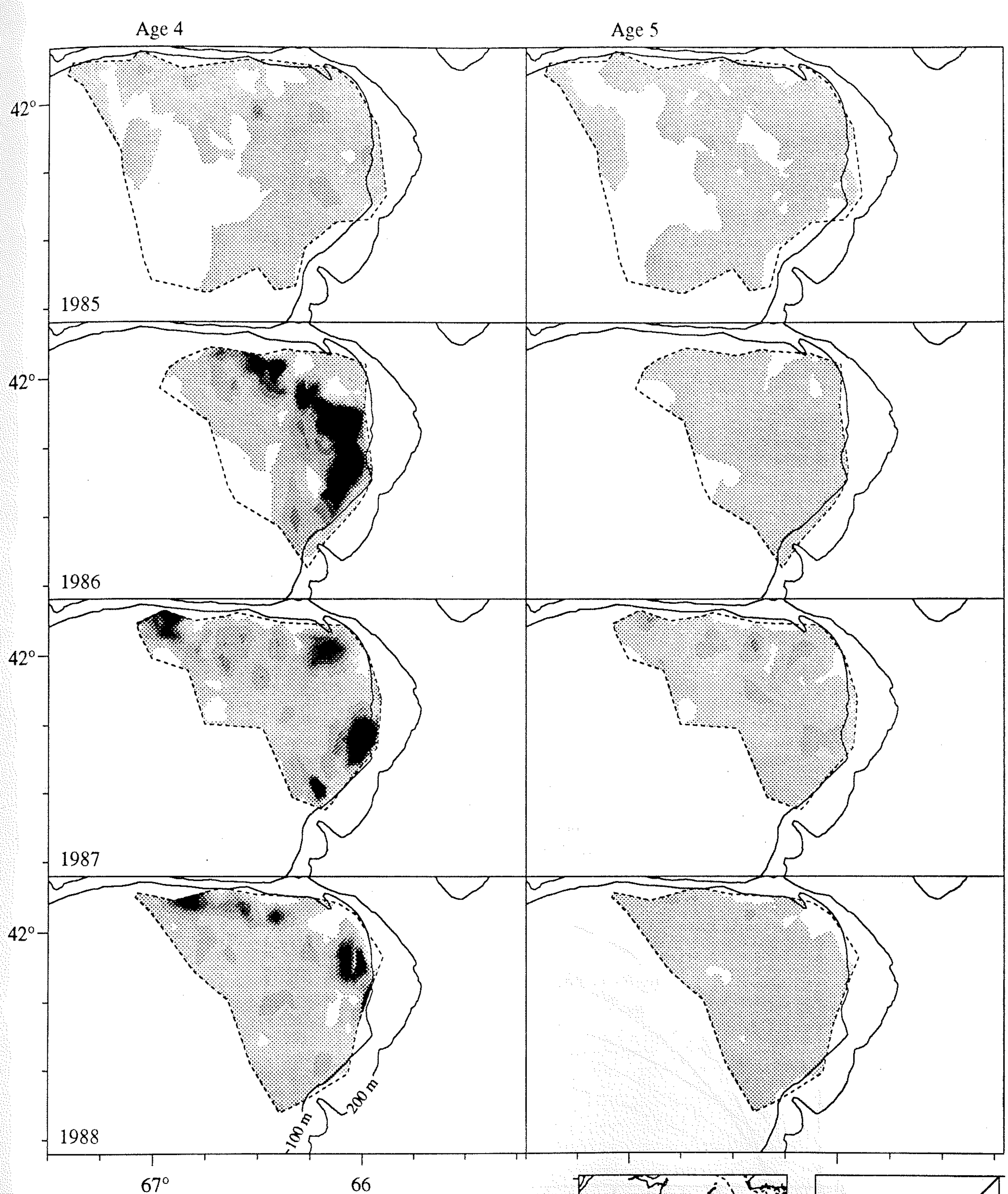


Figure 5. continued. The abundance of age 2 and 3 sea scallops *Placopecten magellanicus* on Georges Bank between 1985-1988. The abundance is calculated as the number of scallops / std tow, and is represented proportionally as a shaded surface. The cohorts may be "read" diagonally by comparing one plot of a particular age with the succeeding plot for the next year (in the next age group). The dashed border line defines the area within which all sampling occurred for the survey.



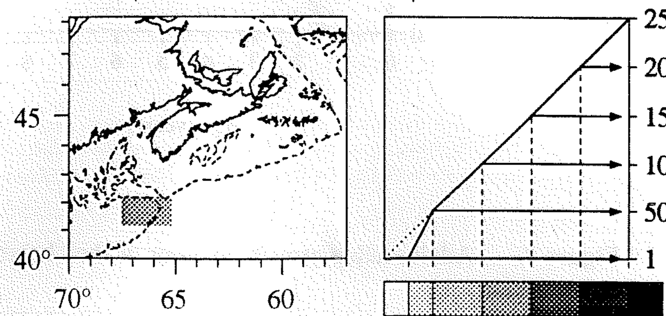


Figure 5. continued. The abundance of age 4 and 5^+ sea scallops *Placopecten magellanicus* on Georges Bank between 1985-1988. The abundance is calculated as the number of scallops / std tow, and is represented proportionally as a shaded surface. The cohorts may be "read" diagonally by comparing one plot of a particular age with the succeeding plot for the next year (in the next age group). The dashed border line defines the area within which all sampling occurred for the survey.

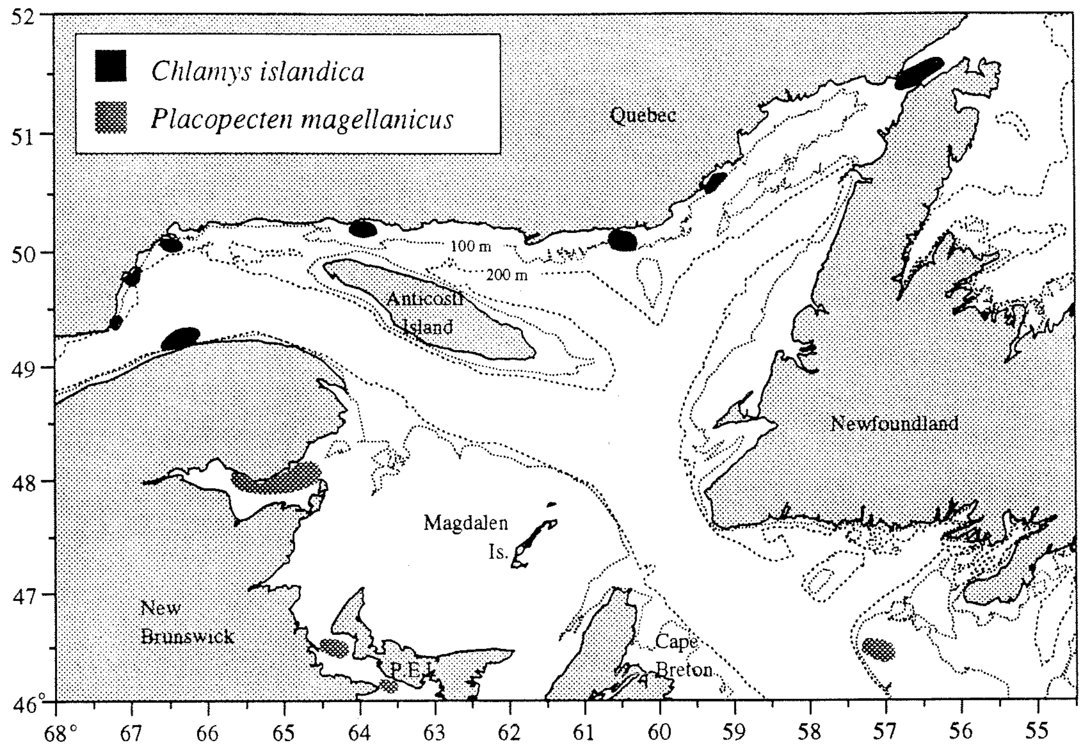


Figure 6. Major areas of fishing activity for Iceland scallop *Chlamys islandica* and the sea scallop *Placopecten magellanicus* in the Gulf of St. Lawerence.

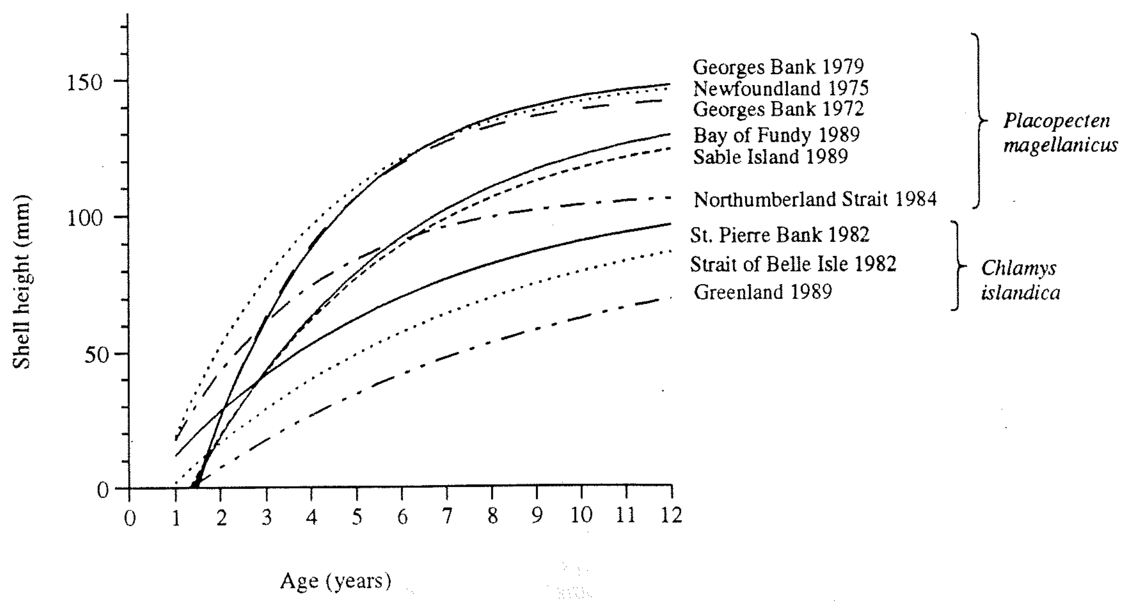


Figure 7. Adult scallop growth, in terms of shell height, estimated for the major commercial beds.

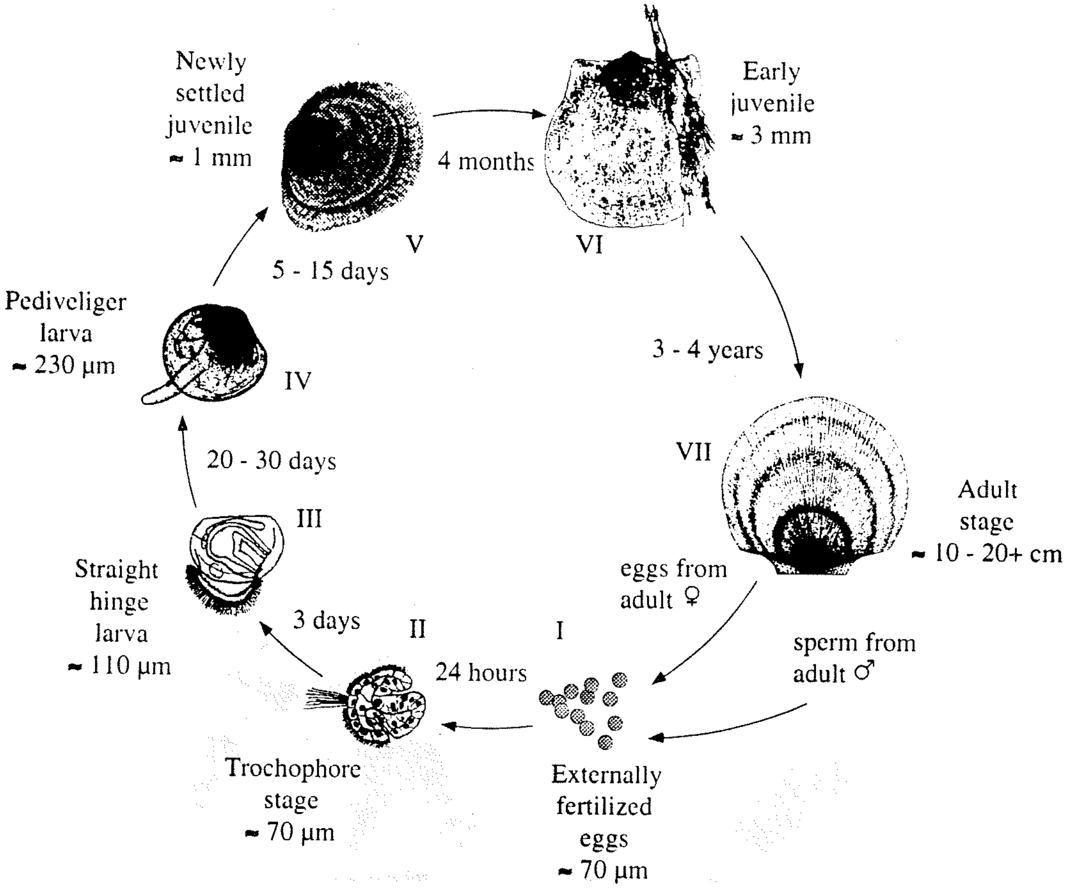


Figure 8. The life cycle of sea scallop *Placopecten magellanicus*. (Figures II, III from Drew 1906, Figures IV, VII from Bourne 1964, Figure V from Culliney 1974, Figure VI from Caddy 1972.)

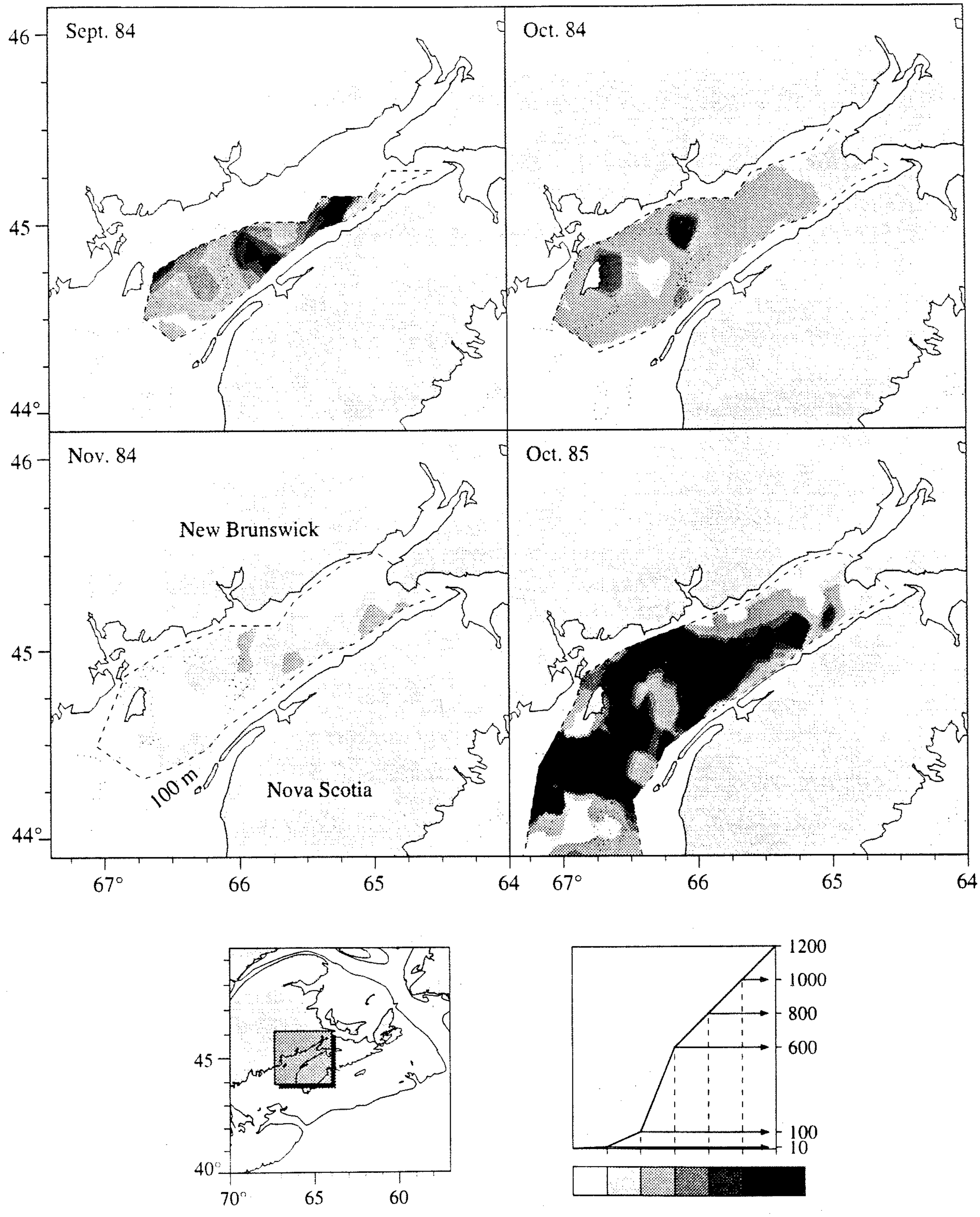


Figure 9. The abundance of larval sea scallop *Placopecten magellanicus* in the Bay of Fundy during the fall of 1984-1985. The abundance is calculated as the number of larvae / m^2, and is represented proportionally as a shaded surface. Note that the increased abundance in Oct. 1985 compared to 1984 is largely due to smaller meshed plankton nets. The dashed border line defines the area within which all sampling occurred for the survey. Data source: Tremblay & Sinclair 1988.

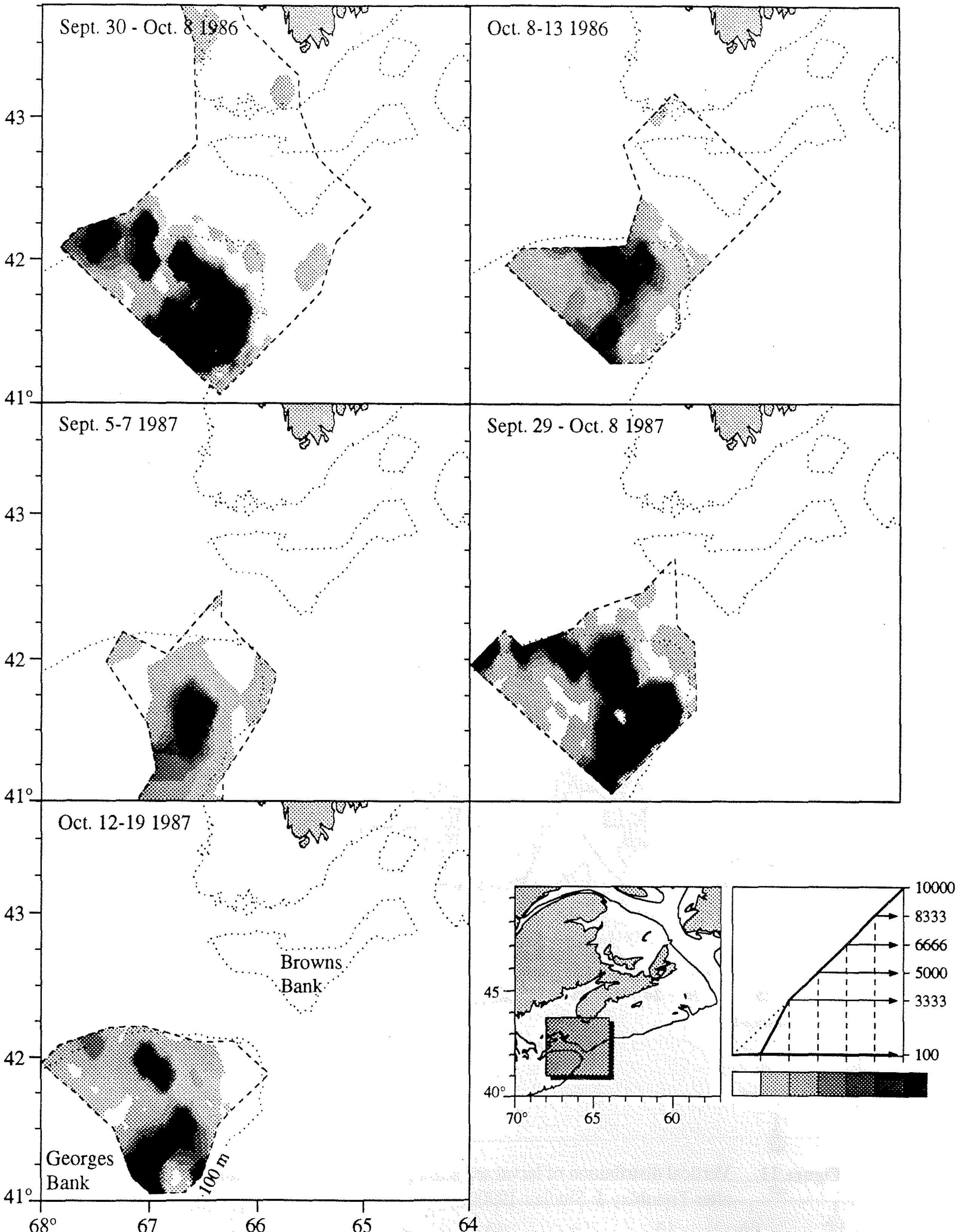


Figure 10. The abundance of larval sea scallop *Placopecten magellanicus* onGeorges Bank during the fall of 1986-1987. The abundance is calculated as the number of larvae / m^2, and is represented proportionally as a shaded surface. The dashed border line defines the area within which all sampling occurred for the survey. Data source: Tremblay & Sinclair 1992.

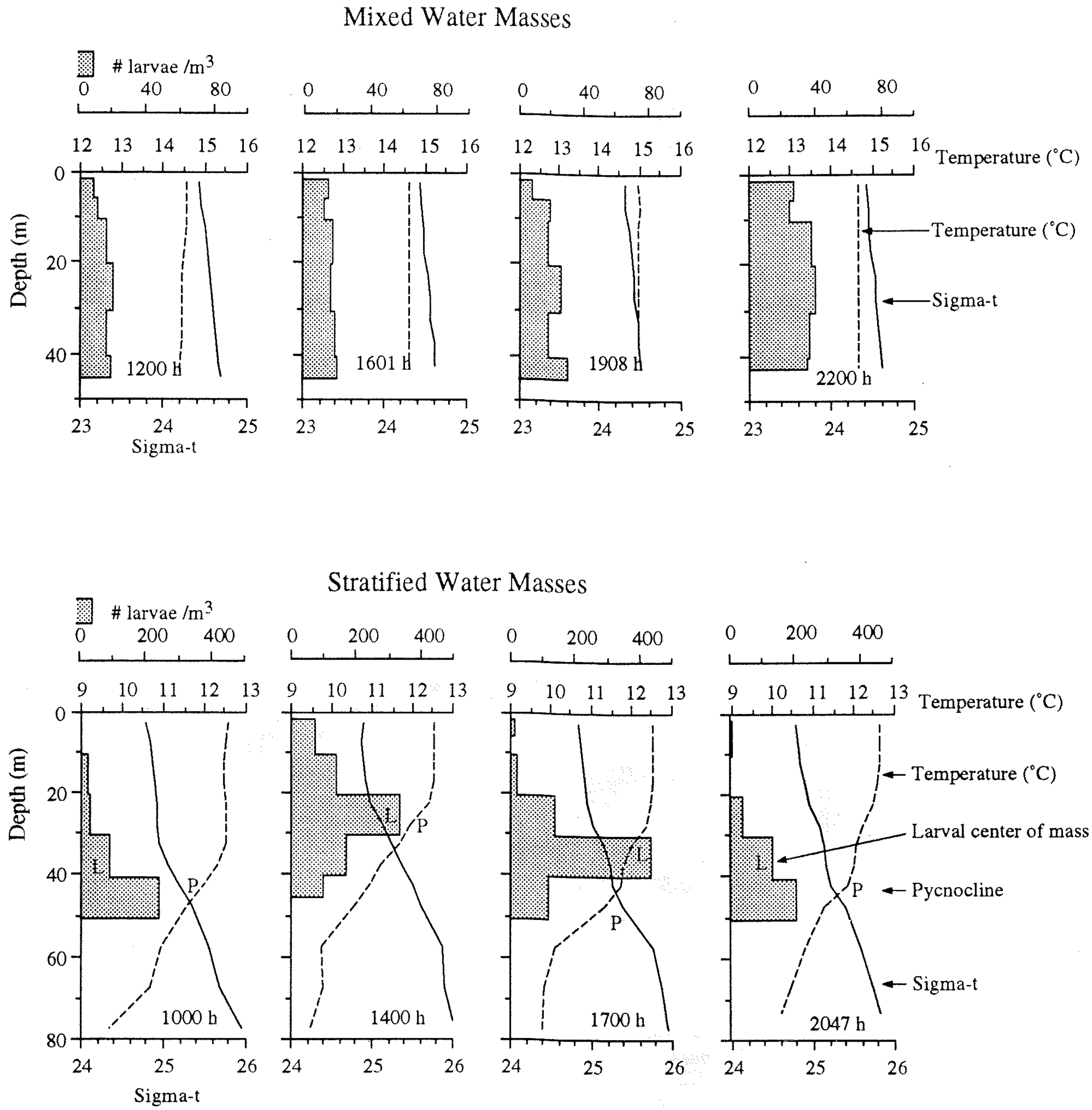


Figure 11. Vertical distribution of larval sea scallop *Placopecten magellanicus* after Tremblay & Sinclair 1990a.

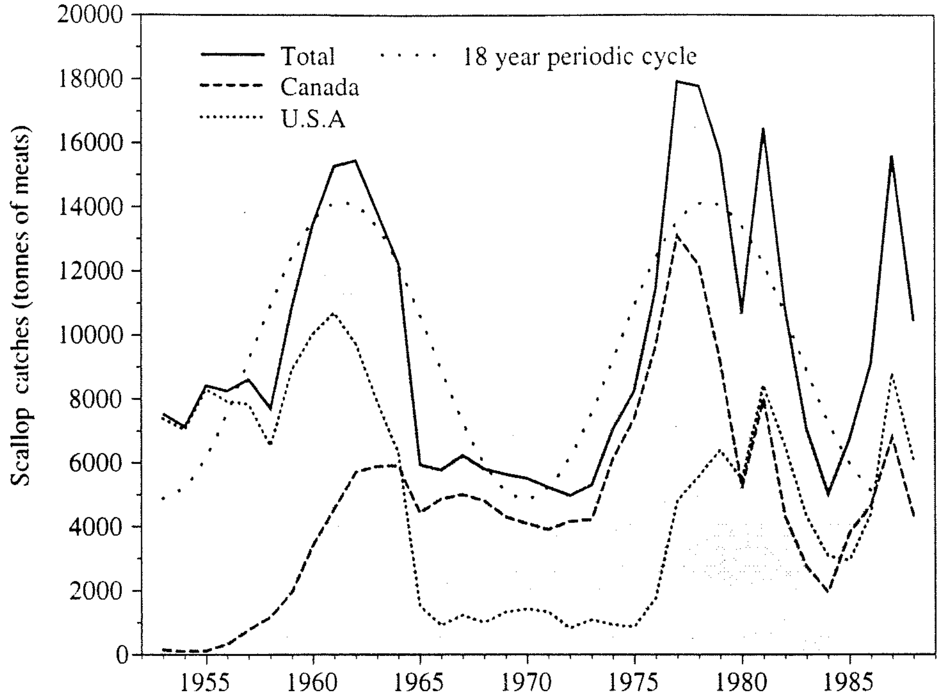


Figure 12. Catches (tonnes of meats) from Georges Bank, NAFO subdivision 5Ze for the period 1953-1988. Source: Sinclair et al., (1985); Mohn et al., (1989). *See also* **Table 2**.

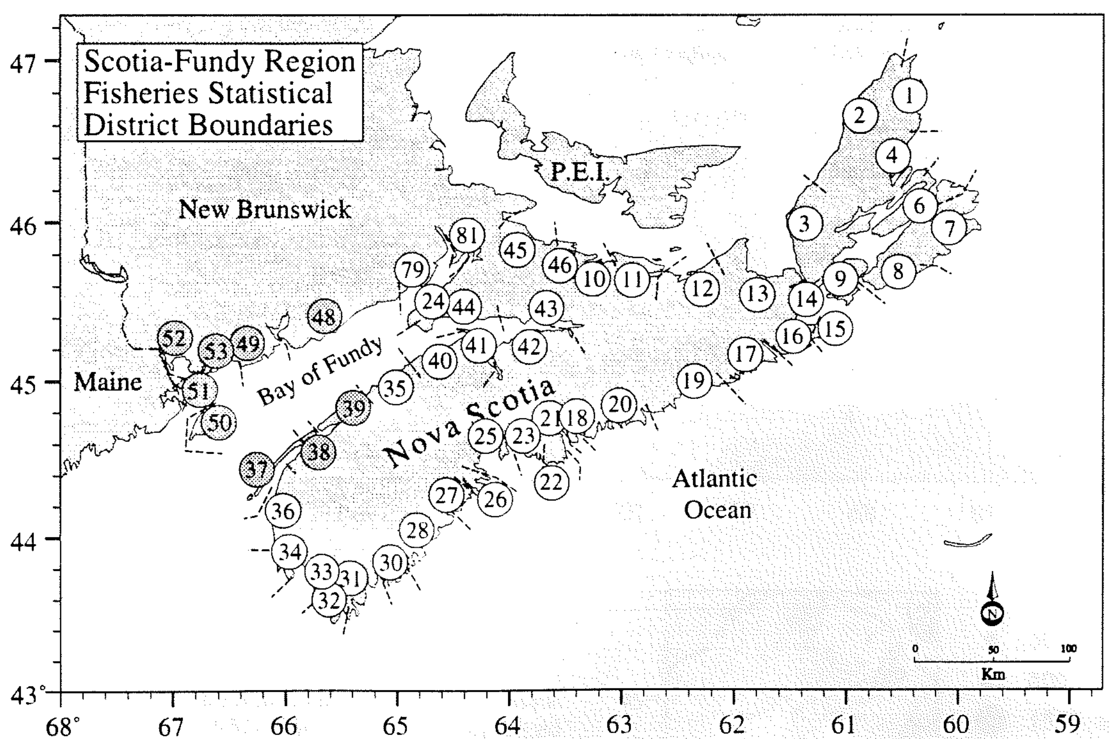


Figure 13. Fisheries Statistical Districts of the Scotia-Fundy Region higlighting the Bay of Fundy inshore zone Statistical Districts 37-39,48-53. *See also* **Figure 14** for inshore zone landings for Statistical Districts 37-39, 48-53.

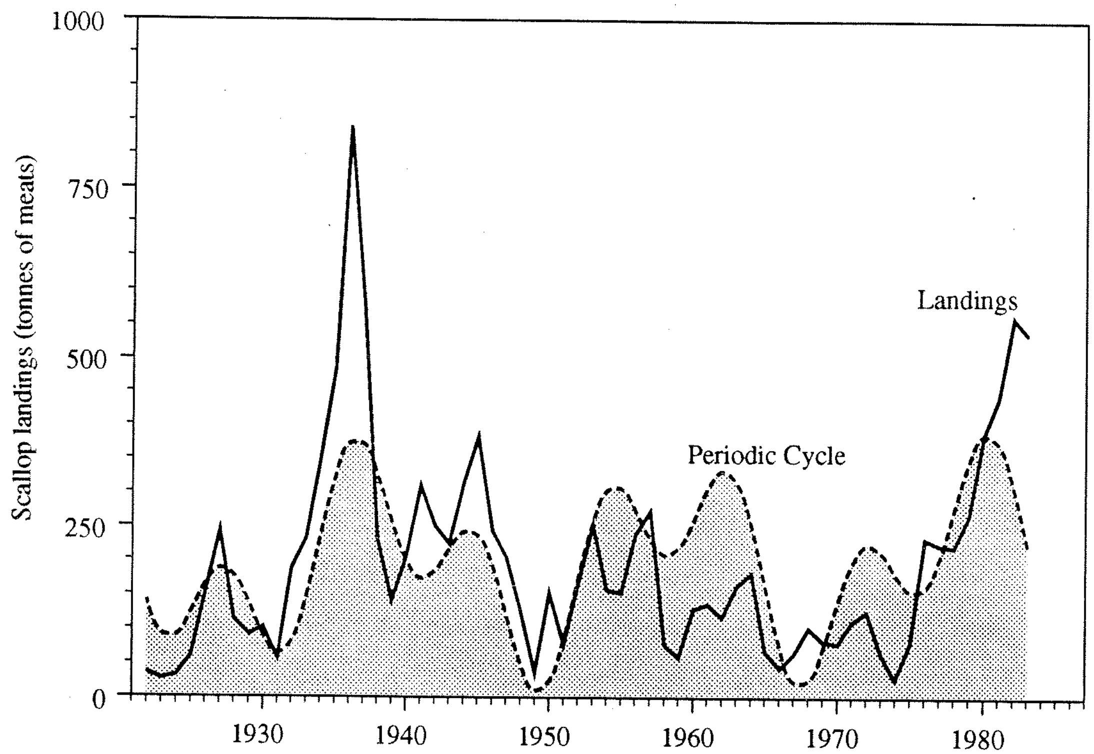


Figure 14. NAFO Subdivision 4Xr (Bay of Fundy) inshore zone landings (tonnes of meats). Source: Statistics Division, Fisheries & Oceans, Halifax. The periodic cycle curve calculated from the landings data, contains periods of 20.7 (major) and 8.9 (minor) years. *See also* **Table 4**.

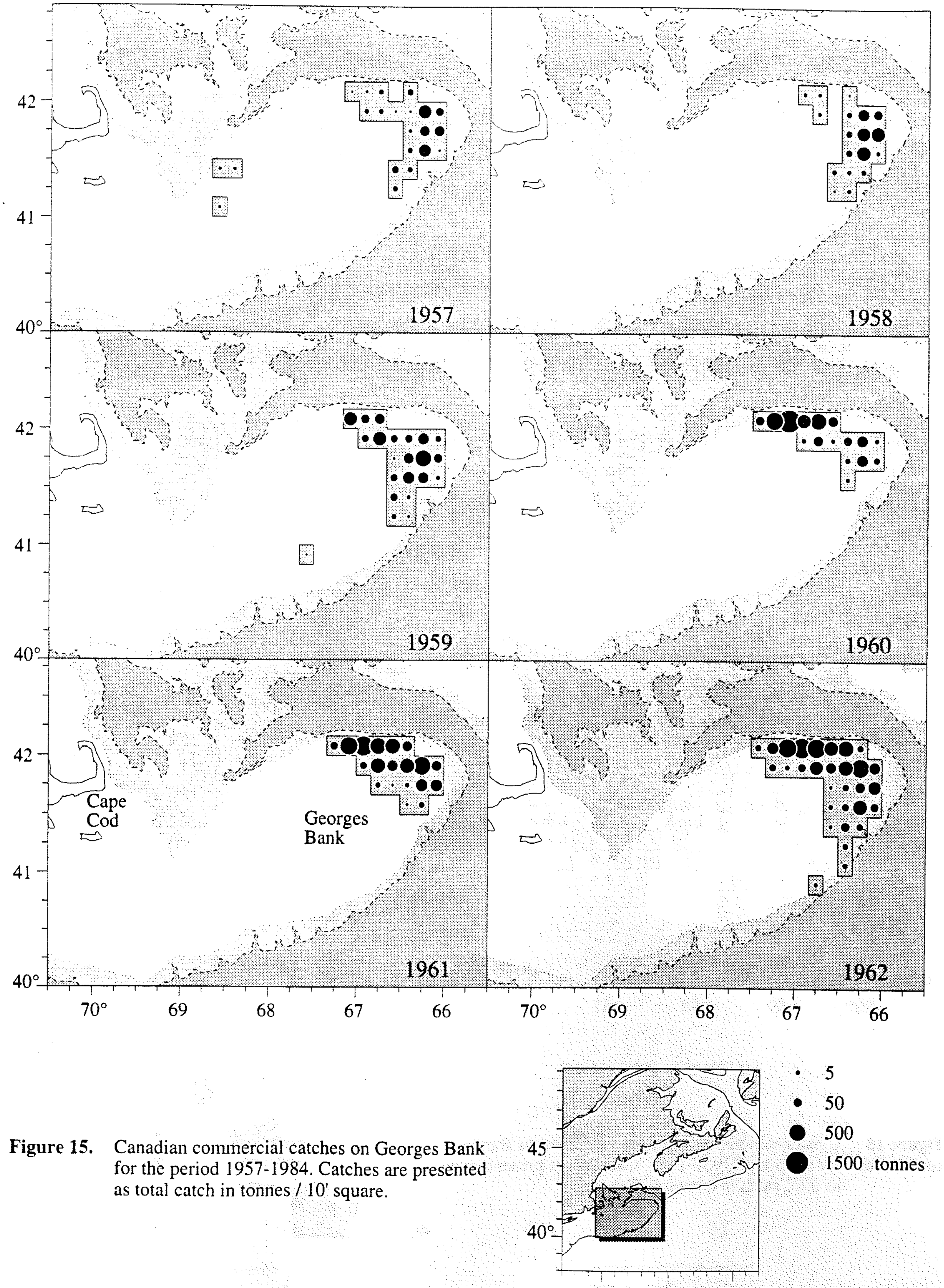
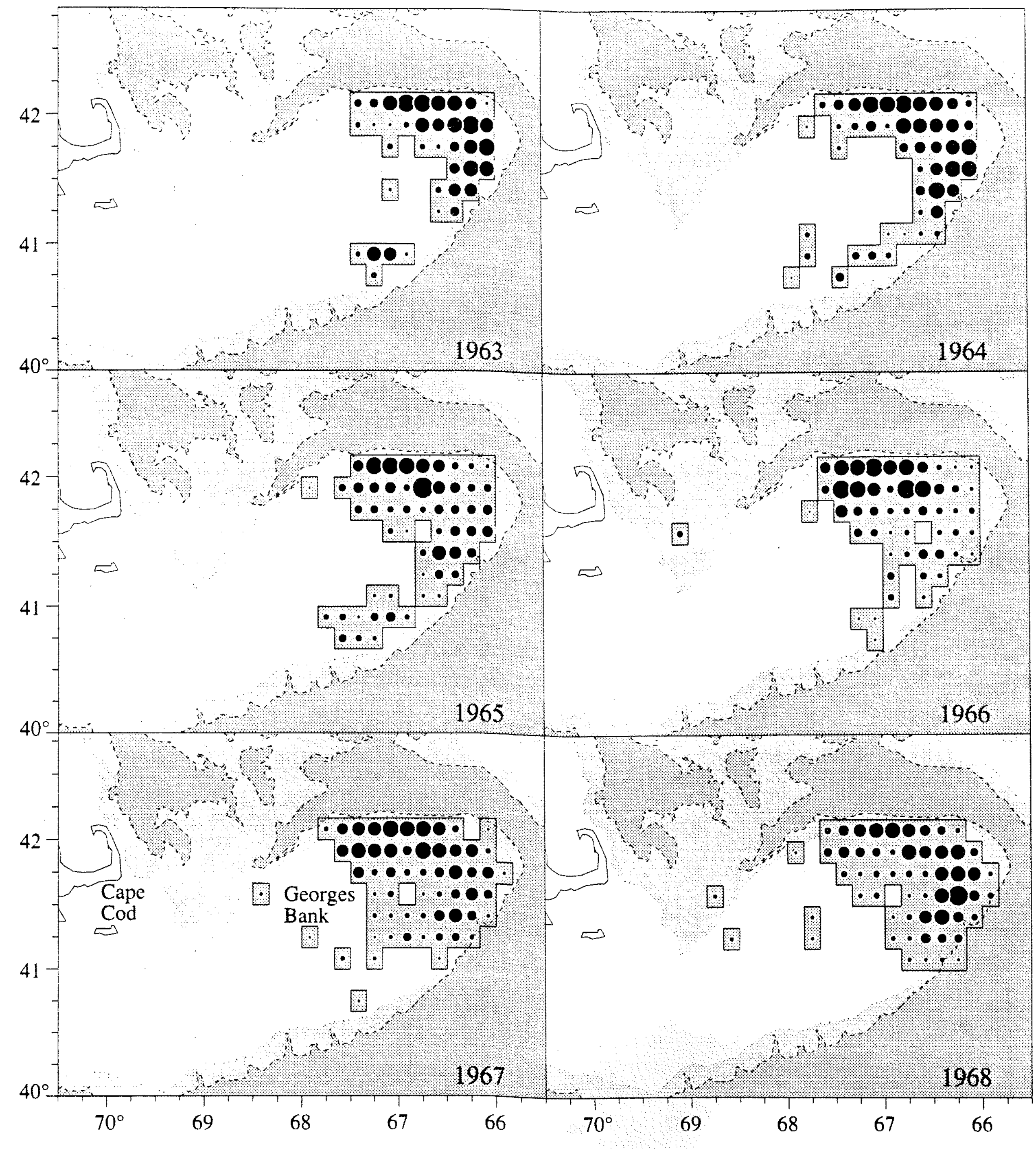


Figure 15. Canadian commercial catches on Georges Bank for the period 1957-1984. Catches are presented as total catch in tonnes / 10' square.



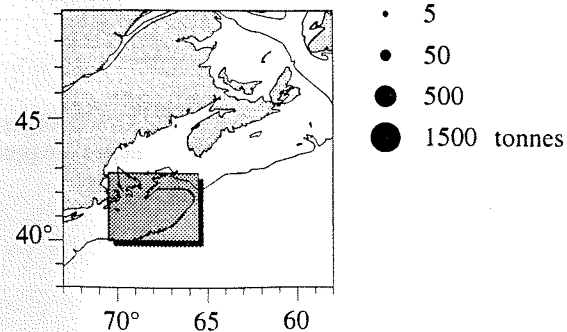


Figure 15 continued. Canadian commercial catches on Georges Bank for the period 1957-1984. Catches are presented as total catch in tonnes / 10' square.

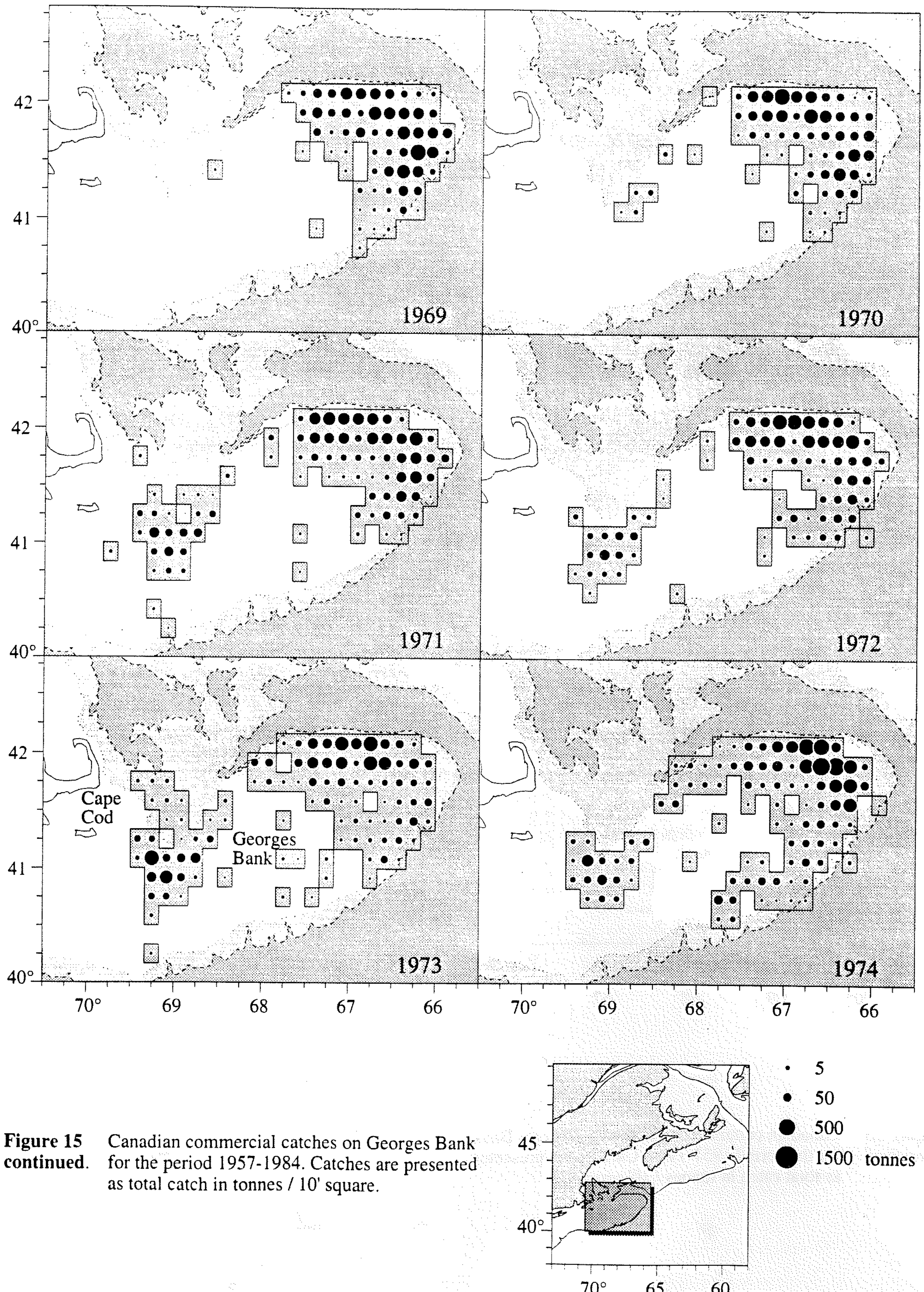


Figure 15 continued. Canadian commercial catches on Georges Bank for the period 1957-1984. Catches are presented as total catch in tonnes / 10' square.

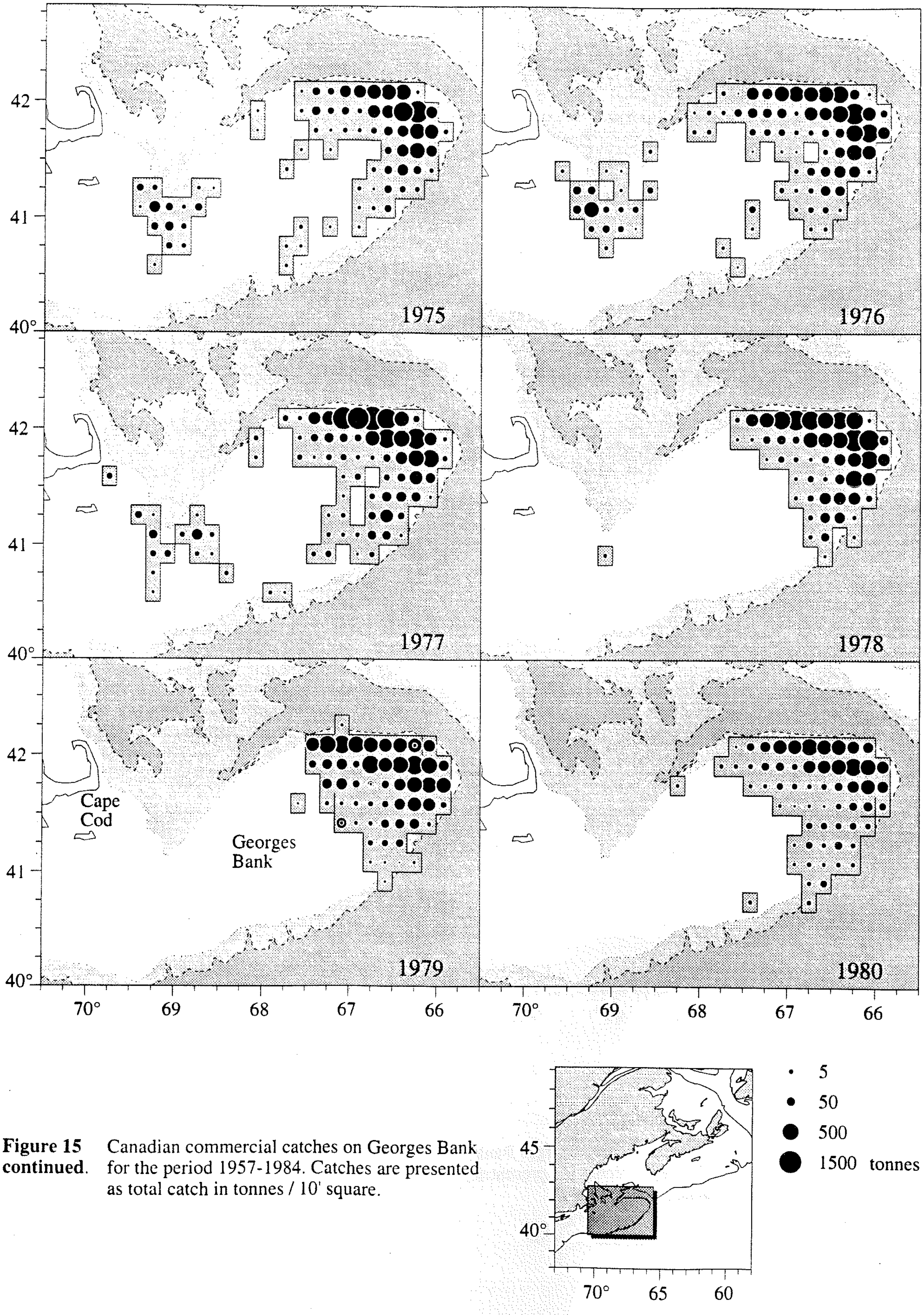


Figure 15 continued. Canadian commercial catches on Georges Bank for the period 1957-1984. Catches are presented as total catch in tonnes / 10' square.

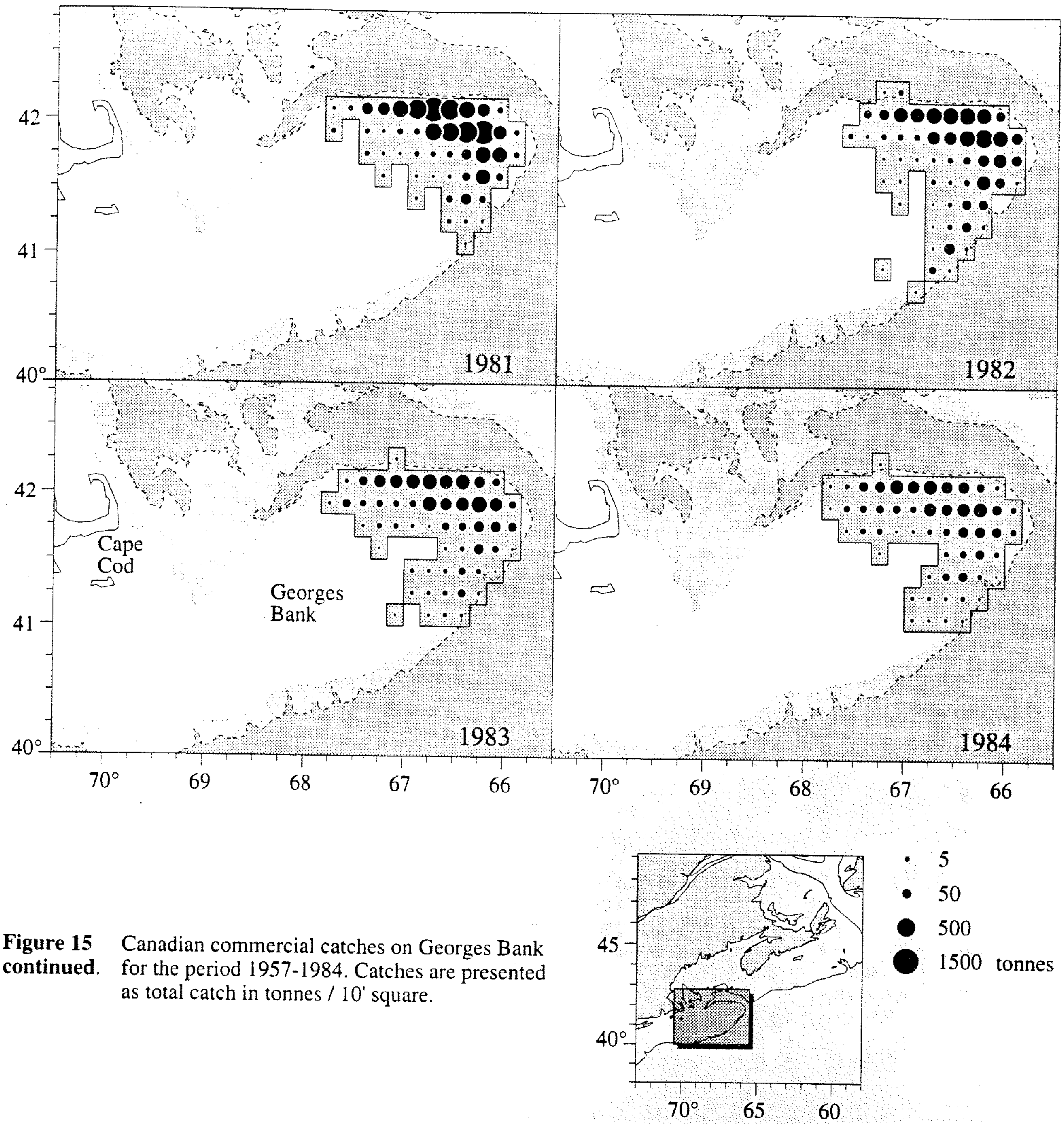
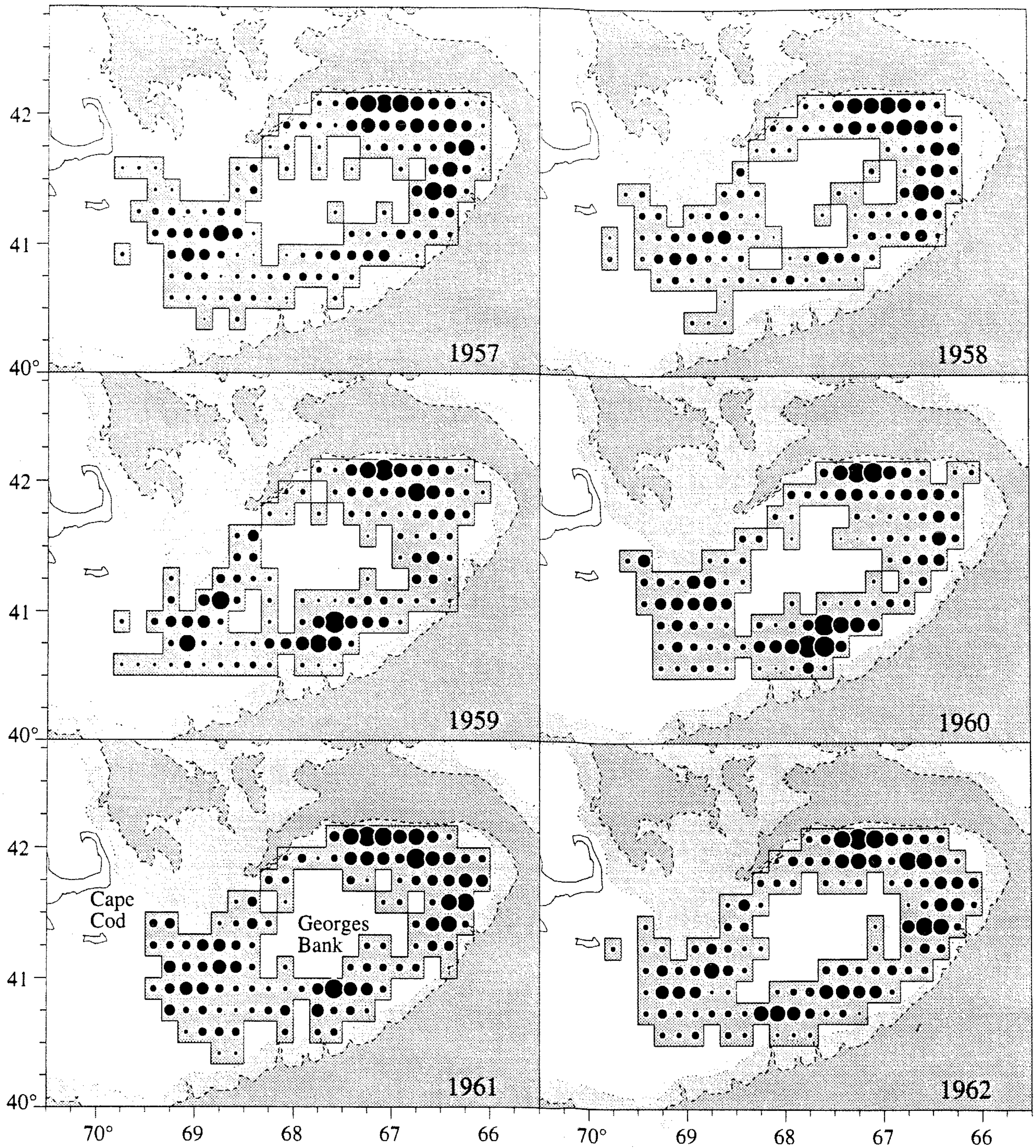


Figure 15 continued. Canadian commercial catches on Georges Bank for the period 1957-1984. Catches are presented as total catch in tonnes / 10' square.



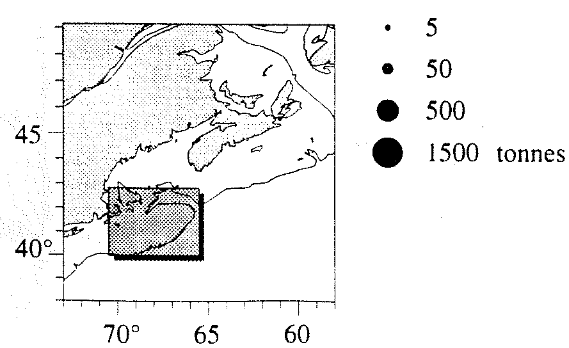


Figure 16. U.S.A. commercial catches on Georges Bank for the period 1957-1980. Catches are presented as total catch in tonnes / 10' square.

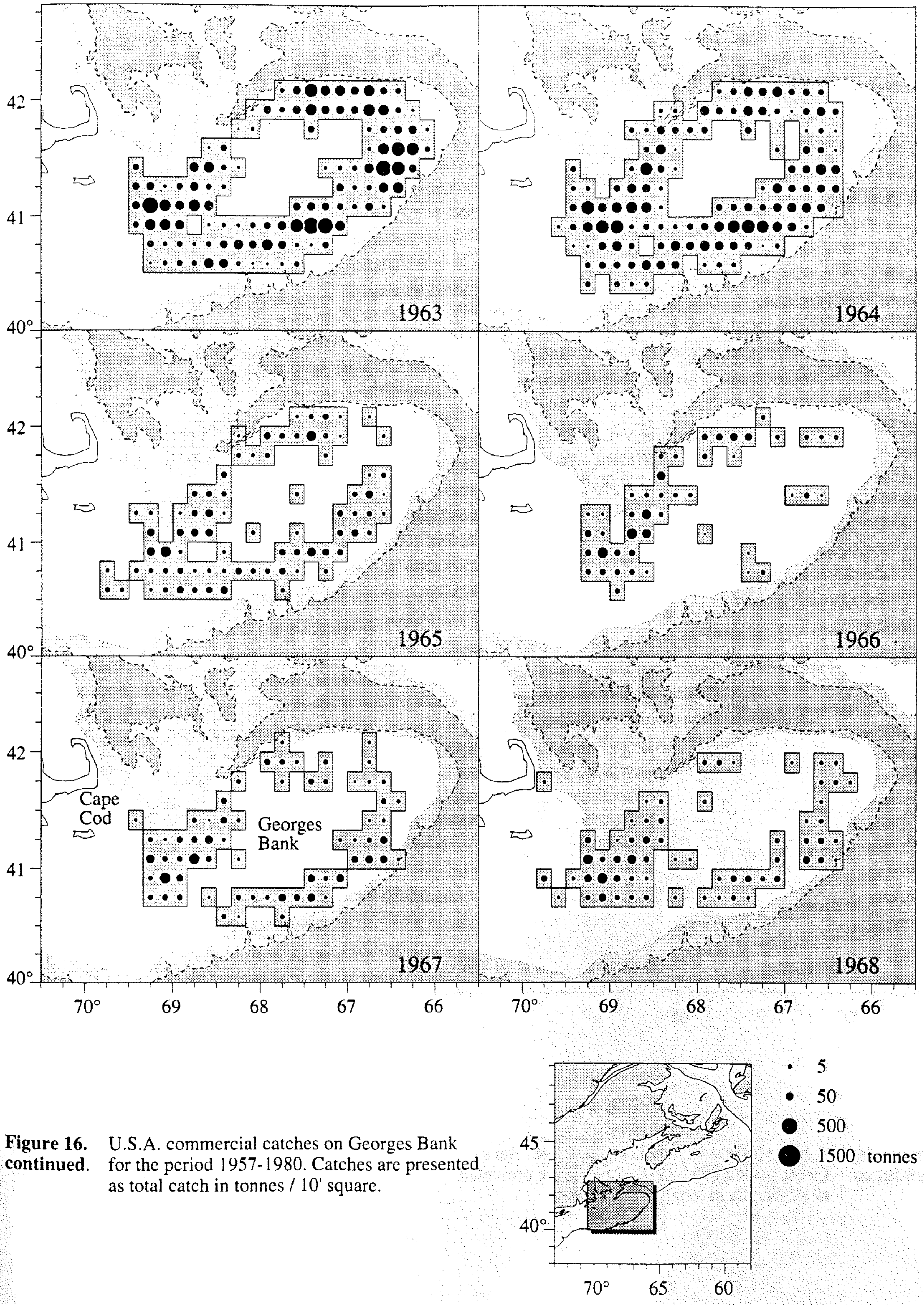


Figure 16. continued. U.S.A. commercial catches on Georges Bank for the period 1957-1980. Catches are presented as total catch in tonnes / 10' square.

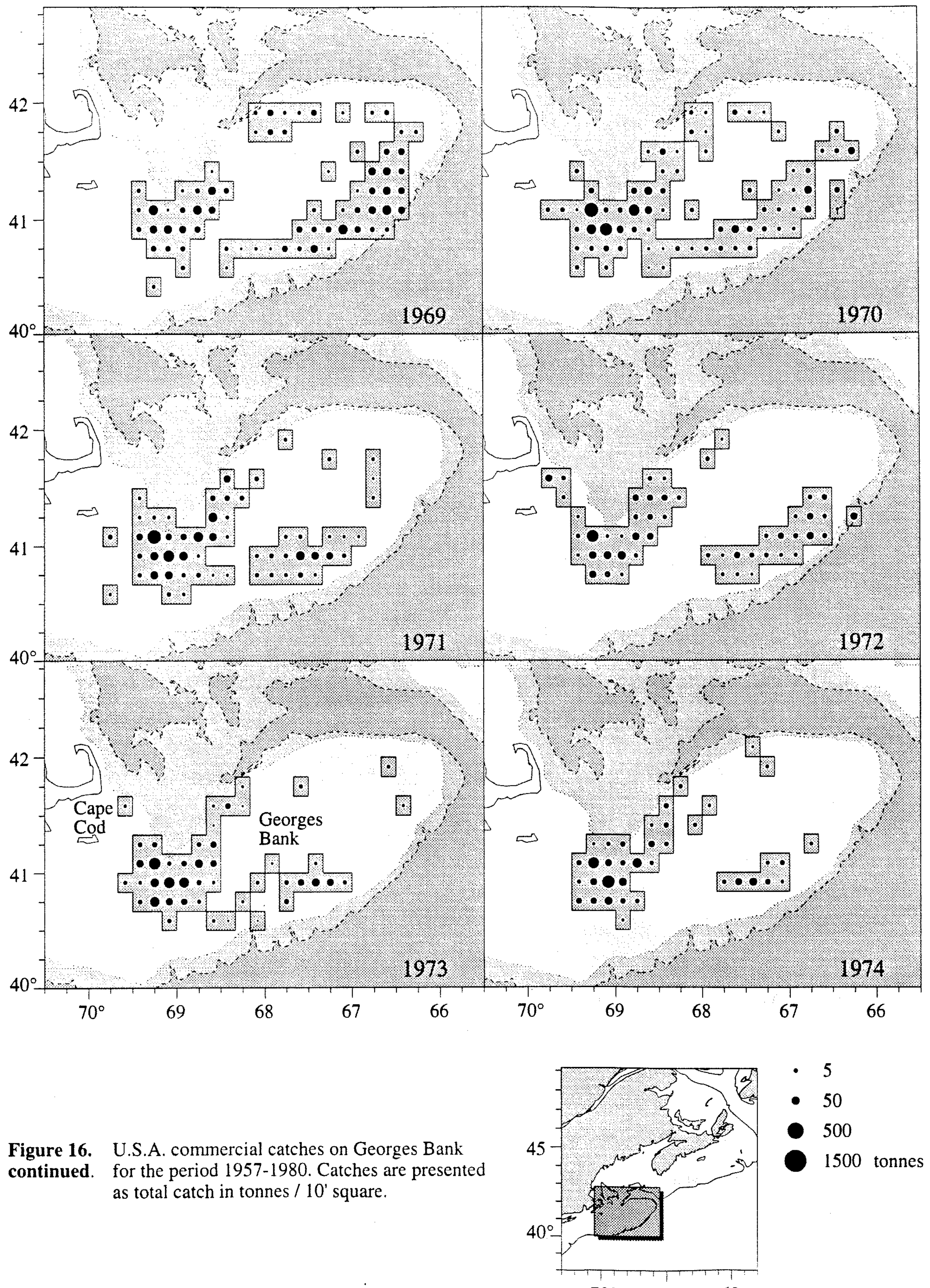
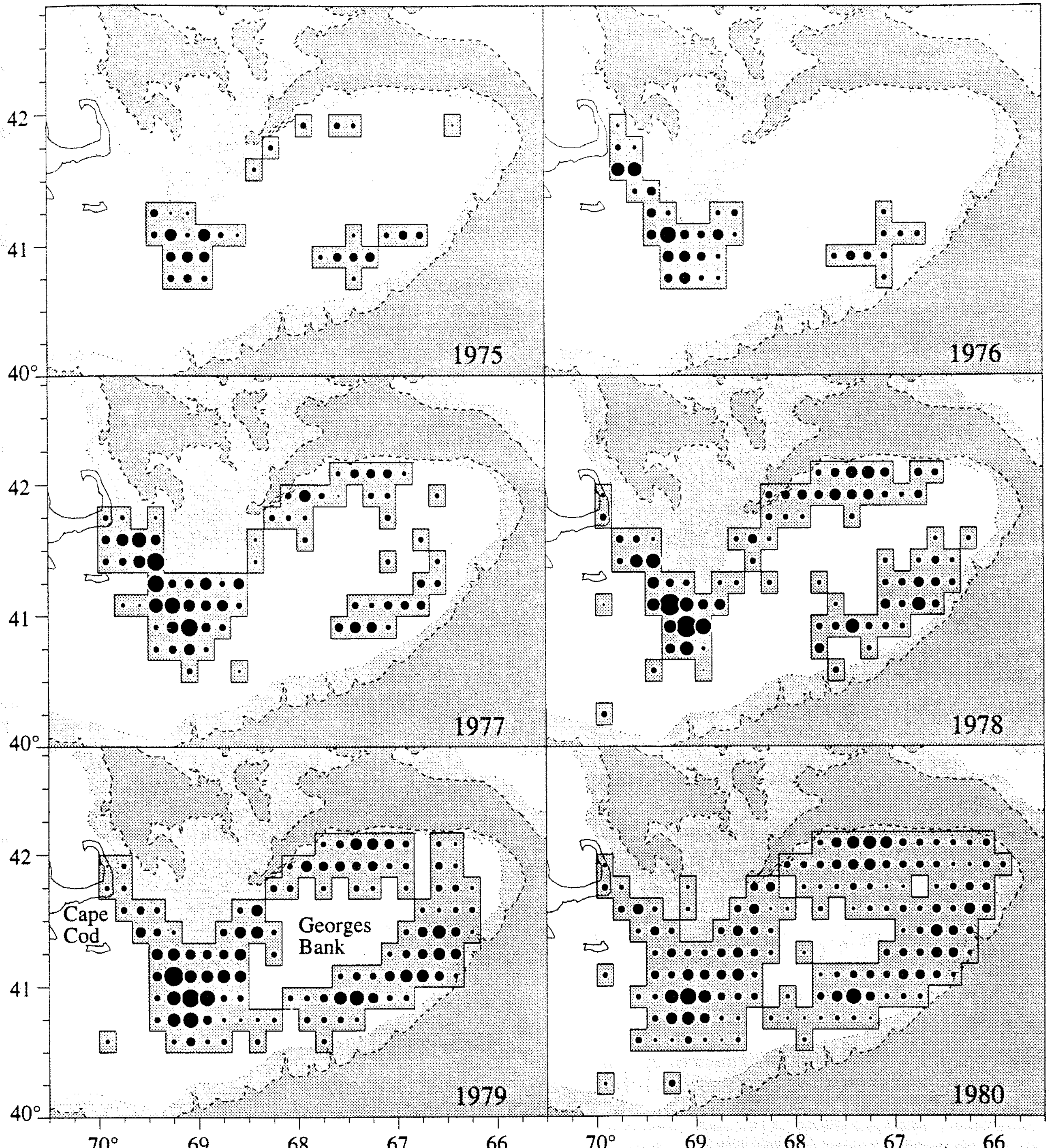


Figure 16. continued. U.S.A. commercial catches on Georges Bank for the period 1957-1980. Catches are presented as total catch in tonnes / 10' square.



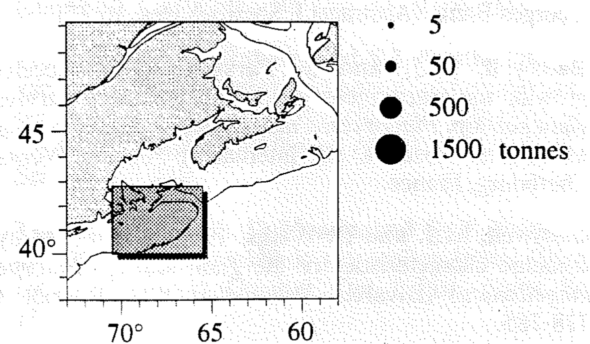


Figure 16. continued. U.S.A. commercial catches on Georges Bank for the period 1957-1980. Catches are presented as total catch in tonnes / 10' square.

References

Abbott, R. T. 1974. American Seashells. The marine Mollusca of the atlantic and pacific coasts of North America. 2nd Ed. Van Nostrand Reinhold Co., Toronto.

Anonymous. 1920. 53rd annual Report of the Fisheries Research Branch, Dept. of the Naval Service, for the year 1919, Appendix I.

Baird, F. T. Jr. 1953. Observations on the early life history of the sea scallop (*Pecten magellancicus*). Maine Dept. Sea Shore Fish., Res. Bull. No. 14, 7 p.

Bertin, J. 1981. Graphics and graphic information-processing. Transl. by W. J. Berg & P. Scott — Walter de Gruyter, New York. 274 p.

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

Brown, B.E, M. Parrack, and D.D. Flescher. 1972. Review of the current status of the scallop fishery in ICNAF division 5Z. ICNAF Res. Doc. 72/113: 13 p.

Cabilio, P., D.L. DeWolfe, and G.R. Daborn. 1987. Fish catches and long-term tidal cycles in Northwest Atlantic fisheries: a nonlinear regression approach. Can. J. Fish. Aquat. Sci. 44: 1890-1897.

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.

Caddy, J.F. 1979. Long-term trends and evidence for production cycles in the Bay of Fundy scallop fishery. Rapp. P.-v. Réun. Cons. int. Explor. Mer, 175: 97-108.

Chouinard, G.A. 1984. Growth of the sea scallop (*Placopecten magellanicus*) on the Tormentine bed, Northumberland strait, Canada. ICES, C.M. 1984/k:40, 7p.

Couturier, C. Y. 1990. Scallop aquaculture in Canada: fact or fancy? World Aquaculture 21: 54-62.

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

Dibacco, C. 1991. Considering a semiannual reproductive cycle for the sea scallop (*Placopecten magellanicus*), on Georges Bank. (Abstract) J. Shellfish Res. 10:271.

Dadswell, M.J. and J. Parsons. 1991. Accelerated growth, increased meat yield, and enhanced survival of giant scallop, *Placopecten magellanicus* grown in suspended culture. Abstract. 8th Internation Pectinid Workshop, Cherbourg, France.

Dadswell, M.J. and D. Weihs. 1990. Size-related hydrodynamic characteristics of the giant scallop, *Placopecten magellanicus* (Bivalvia: Pectinidae). Can. J. Zool. (68): 778-785.

Dickie, L.M. 1955. Fluctuations in abundance of the giant scallop, *Placopecten magellanicus* (Gmelin), in the Digby area of the Bay of Fundy. J. Fish. Res. Bd Can. 12(6): 797-857.

Drew, G.A. 1906. The Habits, anatomyh, and embryology of the giant scallop, *Placopecten tenuicostatus*. Univ. of Maine Studies. No. 6. 71 p.

DuPaul, W.D., J.E. Kirkley, and A.C. Schmitzer. 1989. Evidence of a semiannual reproductive cycle for the sea scallop, *Placopecten magellanicus* (Gmelin, 1791), in the mid-Atlantic region. J. Shellfish Res. 8: 173-178.

Elner, R.W., and G.S. Jamieson. 1979. Predation of sea scallops, *Placopecten magellanicus*, by the rock crab, *Cancer irroratus*, and the American lobster, *Homarus americanus*. J. Fish. Res. Bd Can. 36: 537-543.

Ganong, W.F. 1889. The economic Mollusca of Acadia. Bull. Nat. Hist. Soc. New Brunswick 8: 3-116.

Giguère, M. et B. Légaré. 1989a. Exploitation du pétoncle Côte-Nord du Golfe Saint-Laurent et Gaspésie - 1988. Can. Atl. Fish. Sci. Adv. Comm. Res. Doc. 89/15: 27 p.

Giguère, M. et B. Légaré. 1989b. Exploitation du pétoncle aux Iles-de-la-Madeleine en 1988. Can. Atl. Fish. Sci. Adv. Comm. Res. Doc. 89/14: 32 p.

Lanteigne, M. and L.-A. Davidson. 1988. Status of the northern Gulf of St. Lawrence Iceland scallop (*Chlamys islandica*) stock - 1987. Can. Atl. Fish. Sci. Adv. Comm. Res. Doc. 88/54: 19 p.

Lanteigne, M. et L.-A. Davidson. 1989. Evaluation de la pêcherie du pétoncle géant (*Placopecten magellanicus*) dans le sud du golfe Saint-Laurent - 1988. Can. Atl. Fish. Sci. Adv. Comm. Res. Doc. 89/20: 22 p.

Larsen, P.F. and R.M. Lee. 1978. Observations on the abundance, distribution, and growth of postlarval sea scallops, *Placopecten magellanicus*, on Georges Bank. The Naut. 92: 112-116.

Lescarbot, M. 1609. Histoire de la Nouvelle-France. Paris.

Loder, J.W. 1980. Secondary tidal effects in tidally-energetic shallow seas, with applications to the Gulf of Maine. Ph. D. Thesis, Dalhousie University, Halifax, N.S. 279 p.

MacDonald, B.A. 1984. The partitioning of energy between growth and reproduction in the Giant Scallop, *Placopecten magellanicus* (Gmelin). Ph. D. Thesis, Memorial University, St. John's, Newfld. 202 p.

MacDonald, B.A. and R.J. Thompson. 1986. The influence of temperature and food availability on the ecological energetics of the giant scallop *Placopecten magellanicus* III. Physiological ecology, the gametogenic cycle and scope for growth. Mar. Biol. 93: 37-48.

MacKenzie, C.L. 1979. Biological and fisheries data on sea scallop, *Placopecten magellanicus* (Gmelin). Tech. Ser. Report No. 19, Northeast Fish. Center, Sandy Hook, N.J. 36 p.

Medcof, J.C. 1949. Dark meat and the shell disease of scallops. Fish Res. Bd Can. Prog. Rep. Atl. Biol. Station no. 45: 3-5.

Medcof, J.C. and N. Bourne. 1964. Causes of mortality of the sea scallop, *Placopecten magellanicus*. Proc. Natl. Shellfish. Assoc., 53: 33-50.

Melvin, G.D., M.J. Dadswell, and R.A. Chandler. 1985. Movement of scallops *Placopecten magellanicus* (Gmelin, 1971) (Mollusca: Pectinidae) on Georges Bank. Can. Atl. Fish. Sci. Adv. Comm. Res. Doc. 85/30: 29p.

Merrill, A.S. and R. L. Edwards. 1976. Observations on mollusks from a navigation buoy with special emphasis on the sea scallop *Placopecten magellanicus*. The Naut. 90: 54-61.

Merrill, A.S., J.A. Posgay, and F.E. Nichy. 1966. Annual marks on shell and ligament of sea scallop *Placopecten magellanicus*. Fish. Bull. NOAA, 65(2): 299-311.

Mohn, R.K., G. Robert, and G.A.P. Black. 1989. Georges Bank scallop stock assessment - 1988. Can. Atl. Fish. Sci. Adv. Comm. Res. Doc. 89/21: 26p.

Mottet, M.G. 1979. A review of the fishery biology and culture of scallops. State of Washington Dept. of Fisheries, Tech. Rep. No. 39, 100 p.

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.

Naidu, K.S. 1975. Growth and population structure of a northern shallow-water population of the Giant Scallop *Placopecten magellanicus* (Gmelin). ICES C.M. 1975/K:37.

Naidu, K.S., F.M. Cahill, and D.B. Lewis. 1982. Status and assessment of the Iceland scallop, *Chlamys islandica* in the northeastern Gulf of St. Lawrence. Can. Atl. Fish. Sci. Adv. Comm. Res. Doc. 82/2: 66 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: 25 p.

Pedersen, S.A. 1989. Inshore scallop resources, *Chlamys islandica*, in the Nuuk area West Greenland. NAFO SCR Doc. 89/20.

Posgay, J.A. 1957. The range of the sea scallop. The Nautl. 71(2): 55-57.

Robert, G., M.J. Lundy, and M.A.E. Butler-Connoly. 1989a. Bay of Fundy scallop stock assessment for 1988, a year of record landing. Can. Atl. Fish. Sci. Adv. Comm. 89/18: 38 p.

Robert, G., M.J. Lundy, and M.A.E. Butler-Connoly. 1989b. Scallop fishing grounds on the Scotian Shelf - 1988. Can. Atl. Fish. Sci. Adv. Comm. 89/19: 33 p.

Robinson, W.E., W.E. Wehling, M.P. Morse, and G. McLeod. 1981. Seasonal changes in soft-body component indices and energy reserves in the Atlantic deep-sea scallop, *Placopecten magellanicus*. Fish. Bull. 79: 449-458.

Savage, N. B. 1980. Monitoring of bivalve larvae continues off the New Hampshire coast. Coastal Oceanogr. Climatol. News (Univ. Rhode Island) 2: 44-45.

Schmitzer, A.C., W.D. Dupaul, and J.E. Kirkley. 1991. Gametogenic cycle of sea scallops (*Placopecten magellanicus* (Gmelin, 1791)) in the mid-Atlantic Bight. J. Shellfish Res. 10: 221-228.

Serchuk, F.M. and R.L. Wigley. 1984. USA sea scallop research vessel survey: Status of sea scallop resources in the Georges Bank, Mid-Atlantic, and Gulf of Maine regions and abundance and distribution of Iceland scallops off the Southeastern coast of Cape Cod. Woods Hole Lab. Ref. Doc. 84-34. 74 p.

Serchuk, F.M., P.W. Wood, J.A. Posgay, and B.E. Brown. 1979. Assessment and status of sea scallop (*Placopecten magellanicus)* populations off the northeast coast of the United States. Proc. Nat'l Shellfish. Assoc. 69: 161-191.

Shumway, S. E., R. Selvin, and D. F. Schick. 1987. Food resources related to habitat in the scallop *Placopecten magellanicus* (Gmelin, 1791): a qualitative study. J. Shellfish Res. 6: 89-95.

Shumway, S. E. 1991. Scallops: biology, ecology and aquaculture. Developments in Aquaculture & Fisheries Sciences. 21. Elsevier Science Publishing B.V. Amsterdam. 1095 p.

Sinclair, M., R.K. Mohn, G. Robert, and D.L. Roddick. 1985. Considerations for the effective management of Atlantic scallops. Can. Tech. Rep. Fish. Aquat. Sci. 1382: 113p.

Squires, H.T. 1962. Giant scallops in Newfoundland coastal waters. Bull. Fish. Res. Bd Can., 135: 29 p.

Thomson, R.J. 1977. Blood chemistry, biochemical composition, and the annual reproductive cycle in the Giant Scallop, *Placopecten magellanicus*, from Southeast Newfoundland. J. Fish. Res. Bd Can. 34: 2104-2116.

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.

Tremblay, M. J., L. D. Meade, and G. V. Hurley. 1987. Identification of planktonic sea scallop larvae (*Placopecten magellanicus*) (Gmelin). Can. J. Fish. Aquat. Sci. 44: 1361-1366.

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.

Tremblay, M. J. and M. Sinclair. 1990a. Sea scallop larvae *Placopecten magellanicus* on Georges Bank: vertical distribution in relation to water column stratification and food. Mar. Ecol. Progr. Ser. 61: 1-15.

Tremblay, M. J. and M. Sinclair. 1990b. Diel vertical migration of Sea scallop larvae *Placopecten magellanicus* in a shallow embayment. Mar. Ecol. Progr. Ser. 67: 19-25.

Tremblay, M. J. and M.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.

Vahl, O. 1981. Energy transformations by the Iceland scallop, *Chlamys islandica* (O.F. Müller), from 70°N. I. The age-specific energy budget and net growth efficiency. J. exp. mar. Biol. Ecol. 53: 281-296.

Van Dam, L. 1954. On the respiration in scallops (Lamellibranchiata). Biol. Bull. Mar. Biol. Lab. Woods Hole, 107: 192-202.

Watson, D.F. and G.M. Philip. 1985. A refinement of inverse distance weighted interpolation. Geo-Processing 2: 315-327.

Wigley, R.L. and R.B. Theroux. 1971. Association between post juvenile red hake and sea scallops. Proc. Natl. Shellfish. Assoc., 61: 86-87.

Willis, J.R. 1862. Our edible mollusca. Colonial Review, Halifax, Nov. 29, 1862 (quoted by Ganong, W.F. in Bibliographical & Critical Notice of Willis' Published Papers, p. 414 of Proc. Trans. Nova Scotian Inst. Nat. Sci., 7(4): 1889-1890).