Aspects of the Biology of Arctic Cod *(Boreogadus saida)* and its Importance in Arctic Marine Food Chains

M.S.W. Bradstreet, K.J. Finley,
A.D. Sekerak, W.B. Griffiths,
C.R. Evans, M.F. Fabijan
and H.E. Stallard

Central and Arctic Region
Department of Fisheries and Oceans
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ASPECTS OF THE BIOLOGY OF ARCTIC COD (*Boreogadus saida*) AND ITS IMPORTANCE IN ARCTIC MARINE FOOD CHAINS

by

M.S.W. Bradstreet[1], K.J. Finley[1],
A.D. Sekerak[1], W.B. Griffiths[1],
C.R. Evans[1], M.F. Fabijan[1]
and H.E. Stallard[1]

Central and Arctic Region
Department of Fisheries and Oceans
Winnipeg, Manitoba R3T 2N6

This is the 4th Technical Report
from the Central and Arctic Region, Winnipeg

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[1] LGL Limited, environmental research associates, 22 Fisher Street,
P.O. Box 280, King City, Ontario LOG 1K0

PREFACE

This is the final report of work conducted under the terms of a Department of Supply and Services contract issued to LGL Limited, environmental research associates (DSS Contract No. 01SF.FP430-4-N4621). Scientific authority for the contract was G.D. Koshinsky, Department of Fisheries and Oceans, Freshwater Institute, 501 University Crescent, Winnipeg, Manitoba, R3T 2N6.

The study was bridge-funded by the Department of Supply and Services through its Unsolicited Proposals Program. Contributory funding was provided by the Northern Oil and Gas Action Program (NOGAP), this through the Department of Fisheries and Oceans (Western Region) and the Department of Indian and Northern Affairs. The Department of Fisheries and Oceans Newfoundland Region also provided financial support. The study was one of a series being executed under NOGAP, to assess the implications of hydrocarbon development and production on critical marine habitats of the Canadian Arctic Coastal Shelf (DFO Project B.2), and on those marine species of importance to the survival of higher trophic levels harvested by northerners (IAND Project A.12).

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Arctic cod occur throughout the marine waters of northern North America, as far north as 88°N. Young-of-the-year (Y-O-Y) Arctic cod are planktonic. Older fish (juvenile/adult) are found either (1) dispersed throughout the water column, near the bottom and under ice, or (2) in large schools.

The diet of 708 Y-O-Y Arctic cod from six locations across northern Canada was investigated. The fish ate primarily copepods, i.e. small calanoid and cyclopoid life stages (eggs, nauplii, copepodites).

Otoliths are better than scales for ageing. All otoliths used in the study were aged independently by two observers. We investigated measurement techniques for cod otoliths and found that length measurements through the centrum and parallel to the otolith's sides gave the least observer error. Otoliths consist of alternating bands of opaque and hyaline material. The deposition of these bands of material on otoliths collected over a continuous 12 month period was investigated: each hyaline layer was an annular mark, and counts of these hyaline layers revealed the age of the fish.

The age-frequency distributions of cod otoliths in predator samples (stomachs, feces) and in a few fish collections were compared. There were few differences due to amount of food in a stomach or age of the predator; or due to the season, year, habitat or area of collection. When samples from all predators in a region were grouped together, however, significant inter-regional differences in age-frequency distributions were noted.

Growth of Arctic cod was investigated. Significant inter-regional differences in patterns of otolith growth were found for each of seven cohorts (hatching years 1973-79). Comparisons of annual growth increments for fish up to age 3+ were investigated in blocked analyses of variance. No significant year effects and a marginal effect due to region were noted. There are significant differences in the growth of cod collected in different places, and times, and measurements of annular growth increments in Arctic cod otoliths seem to offer a better potential for detecting growth differences than do calculations of Ford's growth coefficients.

Estimates of the mortality rates of Arctic cod were developed from the numbers of otoliths of different ages in different predators. After age 3 yr, mortality rates increase with age.

The distributions and diets of three migratory marine mammals occurring in the eastern Canadian Arctic (harp seal, narwhal and white whale) indicated that Arctic cod undergo a major inshore movement during the late summer. In some areas this phenomenon occurs yearly, in others irregularly. The dispersed distribution and diet of ringed seals, however, indicates that Arctic cod occur throughout much of the eastern Canadian Arctic on a year-round basis. Based on the results of this study we argue that predators are excellent sampling agents for Arctic cod. The collection of a small number of ringed seal samples across the North over several years would permit an assessment of natural variability in the age structure, growth and mortality of Arctic cod.

Key words: Boreogadus saida; Arctic cod; otoliths; predator-prey relationships; marine mammals; growth; mortality; diets.

RÉSUMÉ

Bradstreet, M.S.W., K.J. Finley, A.D. Sekerak, W.B. Griffiths, C.R. Evans, M.F. Fabijan, and H.E. Stallard. 1986. Aspects of the biology of the Arctic cod (Boreogadus saida) and its importance in arctic marine food chains. Can. Tech. Rep. Fish. Aquat. Sci. 1491: viii + 193 p.

On retrouve le saïda franc dans toutes les eaux de mer de l'Amérique du nord septentrionale jusqu'au 88° N. Les jeunes saïdas de l'année sont à l'état planctonique tandis que les sujets plus âgés (juvéniles, adultes) sont soit dispersés entre la surface et le fond, près du fond et sous la glace, soit en grands bancs.

On a étudié l'alimentation de 708 jeunes saïdas de l'année pris à six endroits différents du Nord canadien; ils se nourrissaient principalement de copépodes, c'est-à-dire de minuscules calanoïdes et cyclopoïdes à divers stades évolutifs: oeuf, nauplius, copépodite.

Les otolithes permettent de déterminer l'âge plus précisément que les écailles. Les otolithes utilisées au cours de l'étude ont été analysées de façon indépendante par deux observateurs. Nous avons essayé différentes techniques de mesure d'otolithes de saïda et avons établi que la mesure de la longueur à partir du centre et parallèlement aux rebords de l'otolithe est celle dont l'erreur d'observation est la moins importante. Les otolithes se composent de bandes de matière opaque et hyaline, en alternance. On a étudié la formation de ces bandes de matière sur les otolithes recueillies au cours d'une période de 12 mois consécutifs: chaque bande hyaline constituait une marque annulaire et le nombre de bandes hyalines représentait bien l'âge du poisson.

Les distributions de fréquences d'âge des otolithes de saïda dans des échantillons prélevés sur des prédateurs (estomac, fèces) et sur quelques saïdas ont été comparées. Il n'y avait que de légères différences, attribuables à la quantité de nourriture dans l'estomac ou à l'âge du prédateur, ou encore, à la saison, à l'année, à l'habitat ou au secteur de collecte. Lorsque les échantillons obtenus de tous les prédateurs d'une même région étaient groupés, on constatait cependant d'importantes différences interrégionales dans les distributions de fréquences d'âge.

On a étudié la croissance du saïda franc: des différences interrégionales sensibles dans les modèles de croissance des otolithes ont été constatées chez chacune des sept (7) cohortes (années de naissance: de 1973 à 1979). On a comparé les augmentations de taille annuelles des poissons jusqu'à l'âge de plus de 3, mais moins de 4 ans, au moyen d'analyses par bloc de la variance. Aucun effet sensible attribuable à l'année de collecte n'a été constaté, mais il y a cependant un effet marginal attribuable à la région. Il y a une différence significative dans ce taux de croissance chez les saïdas recueillies à des endroits et à des moments différents et la mesure de l'augmentation de la croissance des anneaux des otolithes, chez le saida franc, semble mieux convenir pour déceler les différences de croissance que le calcul des coefficients de croissance de Ford.

Les estimations du taux de mortalité du saïda franc ont été établies à partir du nombre d'otolithes d'âge différent retrouvées chez divers prédateurs. Passé l'âge de 3 ans, les taux de mortalité augmentent avec l'âge.

La distribution et le régime alimentaire de trois mammifères marins migrateurs qui se retrouvent dans l'est de l'Arctique canadien (le phoque du Groënland, le narval et le béluga) laissent supposer que le saïda franc se livre à une grande migration vers les côtes à la fin de l'été. À certains endroits, ce phénomène se produit annuellement tandis qu'à d'autres, il est irrégulier. La distribution étendue et le régime alimentaire des phoques annelés indiquent cependant que le saïda franc occupe à longueur d'année la majorité de l'est de l'Arctique canadien. D'après les résultats de cette étude, nous proposons que les prédateurs constituent d'excellents agents d'échantillonnage pour le saïda franc; la collecte d'un petit nombre d'échantillons de phoques annelés dans le Nord sur une période de plusieurs années permettrait d'étudier la variabilité naturelle de la structure d'âge, de la croissance et de la mortalité du saïda franc.

Mots-clés: *Boreogadus saida*; saïda franc; otolithes; predation; mammiféres marins; croissance; mortalité; régime alimentaire.

INTRODUCTION

The Arctic cod (*Boreogadus saida*) is a relatively small, short-lived fish rarely attaining a length of more than 300 mm or an age of seven years. This fish is an extremely important component of Arctic food webs, yet our knowledge of its life history and factors that control its distribution, movements and abundance is still incomplete. To date, we know far more about the importance of Arctic cod in food chains leading to other vertebrates than we do about the fish itself. Thus, our ability to predict the effects of environmental changes in the North on Arctic cod is rudimentary. Consequently, it is not possible to predict the effects of such environmental changes on the many highly valued animals, such as ringed seals, narwhals and a variety of seabirds, that consume Arctic cod.

Figure 1 demonstrates the central role of Arctic cod in food chains leading to arctic marine mammals; similar types of figures in Davis et al. (1980) and Bradstreet and Cross (1982) demonstrate the importance of cod in food chains leading to marine birds. Recent studies on the feeding ecology of vertebrates have confirmed that the Arctic cod is eaten by white whales (*Delphinapterus leucas*), narwhals (*Monodon monoceros*), ringed seals (*Phoca hispida*), bearded seals (*Erignathus barbatus*), harp seals (*Phoca groenlandicus*), walruses (*Odobenus rosmarus*) (occasionally), thick-billed and common murres (*Uria lomvia* and *U. aalge*), black guillemots (*Cepphus grylle*), black-legged kittiwakes (*Rissa tridactyla*), northern fulmars (*Fulmarus glacialis*), Arctic terns (*Sterna paradisaea*), and glaucous (*Larus hyperboreus*), Sabine's (*Xema sabini*), ivory (*Pagophila eburnea*) and Ross' gulls (*Rhodostethia rosea*) (McLaren 1958; Bradstreet 1976, 1977, 1979, 1982; Divoky 1976, 1978, 1984; Lowry et al. 1978, 1980a,b; Springer and Roseneau 1978; Davis et al. 1980; deGraaf et al. 1981; Foy et al. 1981; Bradstreet and Cross 1982; Finley and Gibb 1982; Bradstreet and Finley 1983; Finley and Evans 1983; Finley and Gibb, in press). In many cases, Arctic cod form a significant fraction of the food consumed by the above-mentioned marine mammals and seabirds. Arctic cod are also of indirect importance to polar bears (*Ursus maritimus*) and Arctic foxes (*Alopex lagopus*), since their principal marine food, the ringed seal, relies on Arctic cod as food. The importance of Arctic cod in Arctic marine food webs is underscored by the fact that few or no alternative food sources, in terms of size and energy value, appear to exist.

In contrast to the numerous studies of consumers of Arctic cod, there are few studies that specifically address the biology of this important gadid. Most information on Arctic cod has come from broadly based marine survey programs. Since studying Arctic cod has not normally been a high priority in most survey programs, data arising from survey studies have been of variable quality. Only a few studies have been designed to gather specific data on Arctic cod (e.g. Bain and Sekerak 1978; Lowry and Frost 1981; Bradstreet 1982; Bradstreet and Cross 1982; Craig et al. 1982).

Major obstacles to research on Arctic cod have been a lack of understanding of their significance; logistical problems in sampling the marine system adequately, especially when ice covered; and high costs associated with research in the Arctic. Although the first problem has been overcome, logistical and cost constraints remain. In some respects, the present study was instigated as a result of the last two problems. A substantial part of this study is a departure from traditional methods employed by fishery biologists, especially in Arctic survey programs, in that new approaches to studying Arctic cod are investigated.

We begin by summarizing what is presently known about the distribution and abundance of Arctic cod in North American waters. Much of this information comes from unpublished reports. Then, we present results of new analyses of the diet of young-of-the-year (Y-O-Y) Arctic cod. These cod were captured during standard zooplankton or ichthyoplankton surveys carried out in areas from the Beaufort Sea to the Labrador Sea. The diets of Y-O-Y cod are then compared with the diets of older (juvenile/adult) cod for which considerable information already exists.

Although Y-O-Y Arctic cod can be caught with the standard gear used in many marine survey programs, sampling of older (juvenile or adult) Arctic cod is difficult or impossible in many situations. One of our approaches was to use Arctic cod predators (marine mammals, seabirds and other fish) as sampling agents. Because these predators are adapted to feed on cod, we can learn much by examining the cod that they catch. Recovery of cod from predator samples (stomachs and feces) allowed us to sample cod in a variety of geographic areas, and, importantly, at all times of year. Otoliths are the primary material that can be obtained from predator samples. They are resistant bony plates from the inner ear of teleost fish. Otoliths are often found in predator samples when other fish remains are digested and of little or no use. Through correlations between otolith size and fish size, analyses of annual growth in otoliths, and analyses of the age-frequency distributions of otoliths in different samples, considerable new information on Arctic cod can be obtained. A major emphasis of this study was to assess the use of annular growth rings in otoliths for determining growth in past years. The major interest in this concept is that, if past growth of Arctic cod can be accurately estimated, the effects of major environmental change on Arctic cod growth can perhaps be examined. We also investigated mortality rates of Arctic cod by examination of otoliths found in predator samples.

We then synthesize many of these data, along with information on the distribution and behaviour of major (marine mammal) predators, to obtain insight into predator-prey relationships and the biological cycles of both the prey and the predators. We conclude the study by formulating specific research plans for the future that are feasible with modest expenditure, and will further the overall understanding of how Arctic cod function in relation to their biotic and abiotic surroundings.

DISTRIBUTION OF ARCTIC COD IN NORTH AMERICAN WATERS

Bain and Sekerak (1978) summarized most distribution records of Arctic cod available to 1977. Since that time there have been a number of other summaries of Arctic cod but all had rather local perspectives or were literature reviews. For example, Sekerak (1982a) summarized information on Arctic cod in Alaska, Craig et al. (1982) synthesized some data on Arctic cod in the Alaskan Beaufort Sea, and Johnson (1983a) reviewed much information on Arctic cod in a discussion paper for the Beaufort Sea EARP hearings in Inuvik, N.W.T. The following is also a review of present information, but attempts are made to synthesize data and to identify uncertainties about Arctic cod throughout the North American Arctic, from the Bering Sea to the northwest Atlantic.

BERING SEA

Arctic cod are normally absent in the southern and central Bering Sea but occur in some numbers farther north in Norton Sound and in waters adjacent to St. Lawrence Island (Fig. 2). Two surveys, both using trawls for sampling, found Arctic cod to be common in Norton Sound (Pereyra and Wolotira 1977). However, Barton (1979) sampled inshore waters of the same area with gill nets and seines and captured no Arctic cod. (As will be shown repeatedly, gill nets do not appear to be effective in capturing Arctic cod in most circumstances.) Lowry and Frost (1981), using a moderate-size trawl, found Arctic cod in low numbers in slightly over 50% of their samples from waters adjacent to St. Lawrence Island. A substantial number of feeding studies have been undertaken in the Bering Sea. To our knowledge, Arctic cod have been reported in predator stomachs collected only in the northern portions of the sea (Frost and Lowry 1980; Divoky 1981; Hunt et al. 1981; Lowry and Frost 1981).

The southern limits of Arctic cod distribution may be modified by water temperature. Particularly cold or warm years, or changes in oceanic circulation patterns, may affect the distribution of Arctic cod (Moskalenko 1964; Ponomarenko 1968). Andriashev (1964) stated that Arctic cod frequent the White Sea only during cold years, and McKenzie (1953) reported Arctic cod in the Gulf of St. Lawrence only in winter. Lowry and Frost (1981) found that in the northern Bering Sea, Arctic cod were more abundant in winter. The southern limit of Arctic cod distribution and their abundance probably vary with time. For practical purposes, Arctic cod do not appear to occur south of about 62°N in the Bering Sea (Fig. 2). They also appear to be rare or absent in nearshore shallow-water areas.

CHUKCHI SEA

Evidence to date suggests that Arctic cod are found throughout the Chukchi Sea, although local and regional conditions may affect their distribution. Alverson and Wilimovsky (1966) reported that the Arctic cod was the most common fish species in trawl catches in the southeastern Chukchi Sea, near Point Hope. Similar results were obtained in trawl catches in Kotzebue Sound by Pereyra and Wolotira (1977) and Wolotira et al. (1979). The Arctic cod was again the most abundant fish in 33 trawls in the northeastern Chukchi Sea (Lowry and Frost 1981).

Few studies have reported Arctic cod from nearshore areas of the Chukchi Sea. As in the northern Bering Sea, they may be uncommon in such regions, or not caught by the sampling techniques usually used. In the northeastern Chukchi Sea near Point Lay, Craig and Schmidt (1985) reported that Arctic cod were captured in nearshore areas in traps and fyke nets but only exceptionally in gill nets. (One specimen was captured in a gill net in a river estuary in winter.) Fechhelm et al. (1984) reported Arctic cod to be common in trawl catches offshore from Point Lay and Cape Lisburne, and near Wainwright; gill nets were set in offshore areas but no Arctic cod were caught. Arctic cod have been found in predator stomachs collected near Cape Thompson (Johnson et al. 1966; Swartz 1966; Springer et al. 1984), and near Cape Lisburne (Springer et al. 1984).

Most of the "offshore" surveys of the Chukchi Sea have, in reality, been relatively close to shore. Much of the east-central portion of the sea has not been studied (Fig. 2). Arctic cod probably occur throughout this large unsampled area.

Planktonic Y-O-Y Arctic cod were common in Ledyard Bay, north of Cape Lisburne (Quast 1974).

BEAUFORT SEA

The margins of the Beaufort Sea have been sampled through numerous studies (Kendel et al. 1975; Griffiths et al. 1977; Bendock 1979; Broad 1979; Craig and Haldorson 1981; Lawrence et al. 1984). In many, sampling was conducted from small boats from shoreline camps using methods not conducive to the capture of Arctic cod. In addition, a number of the studies were performed in areas of freshened water influenced by the Mackenzie River. These conditions appear generally to repel Arctic cod. For the above reasons, reports of Arctic cod in the Beaufort Sea are few relative to the number of aquatic investigations performed in the region.

Some of the early reports of Arctic cod in the North American Arctic were from the Beaufort Sea. For example, Murdoch (1885) reported Arctic cod in native subsistence catches near Barrow. MacGinitie (1955) also reported Arctic cod near Point Barrow. Recent trawl samples strongly suggest that Arctic cod are found throughout the Alaskan Beaufort Sea in "offshore" waters; Lowry and Frost (1981) reported Arctic cod to be the most abundant fish in 23 samples collected in summer about 50-150 km from land (Fig. 3). Winter sampling documented Arctic cod 175 km offshore (Craig et al.

1982). Inshore studies along the Alaskan coastline have reported Arctic cod in a number of areas from Kaktovik to west of Prudhoe Bay (Bendock 1979; Moulton et al. 1980, 1985; Craig et al. 1982; Woodward-Clyde Consultants 1982).

In the Canadian Beaufort Sea, nearshore studies have rarely reported Arctic cod, except near Herschel Island. Kendel et al. (1975), in sampling over 40 locations along the Yukon coast twice over two years, captured only one Arctic cod (near Herschel Island). Steigenberger et al. (1975) also captured a single Arctic cod at Herschel Island. Walters (1953a) recorded Arctic cod near Herschel Island. McAllister (1962) captured Arctic cod from a number of areas near Herschel Island and also at one site near the international border. Other studies in this area have not employed trawls, which could account for the scarcity of reports of cod in the Herschel Island region.

Hunter (1979) reported that Arctic cod occur along Tuktoyaktuk Peninsula. Envirocon Ltd. (1977) captured one Arctic cod in shallow water off the outer Mackenzie Delta. Percy (1975) sampled about 30 sites adjacent to the Mackenzie Delta (excluding sites within the delta per se) during 1974 and 1975 and did not capture any Arctic cod. Byers and Kashino (1980) surveyed fish in Kugmallit Bay and Tuktoyaktuk Harbour. They did not capture any Arctic cod, although a number of polar cod, *Arctogadus glacialis*, were present. [This is an unusual report of the presence of polar cod but identity of the specimens was apparently confirmed by D. McAllister of the National Museums of Canada (Byers and Kashino 1980).] Jones and Den Beste (1977) reported a single Arctic cod captured at one of 12 sampling stations near Tuft Point on the Tuktoyaktuk Peninsula. Extensive sampling of Tuktoyaktuk Harbour, and to a lesser extent Kugmallit Bay, between July 1979 and March 1981 did not reveal the presence of Arctic cod (Bond 1982). In a large survey of fishes along the Tuktoyaktuk Peninsula involving about 80 sites from the eastern edge of the Mackenzie Delta to Cape Dalhousie, Lawrence et al. (1984) encountered single Arctic cod on only two occasions. Admittedly most sampling in the above studies was performed with gill nets and seines, methods that are not conducive to Arctic cod capture, but it is thought that Arctic cod are indeed uncommon in most nearshore waters of the Canadian Beaufort. One hypothesis is that their scarcity in this area is due to widespread brackish water caused by Mackenzie River outflow.

Studies comparable to the offshore surveys of Lowry and Frost (1981) in the Bering Sea have not been performed in the Canadian Beaufort; hence, distribution of Arctic cod in this region is poorly documented. Galbraith and Hunter (1979) captured small numbers of Arctic cod in about 35 trawl samples in Mackenzie Bay in 1974 and 1975. Trawl surveys are presently being executed in offshore areas as part of a multiyear study by Department of Fisheries and Oceans, Freshwater Institute; Arctic cod were captured in offshore waters in 1984 (M. Lawrence, Department of Fisheries and Oceans, Winnipeg; personal communication).

A substantial number of feeding studies have reported Arctic cod in the diets of vertebrate predators in the Beaufort Sea. Arctic cod have been found in the diets of white whales taken near Barrow (Seaman et al. 1982), ringed seals taken at various locations from Kaktovik to Barrow (Lowry et al. 1980a; Frost and Lowry 1981), and a variety of seabirds taken at several sites (Divoky 1984). Such studies verify the widespread occurrence of Arctic cod in the Alaskan Beaufort Sea. Similar trophic studies have not been performed in the Canadian Beaufort Sea.

In contrast to the information concerning juvenile and adult Arctic cod, Y-O-Y Arctic cod are better known from the Canadian than the Alaskan Beaufort Sea. More studies have sampled offshore zooplankton or ichthyoplankton in the Canadian area. In Alaska, Y-O-Y Arctic cod were relatively common in Simpson Lagoon (Craig et al. 1982). In the Canadian Beaufort, Y-O-Y Arctic cod were widespread (present at all 22 sampling sites) throughout Mackenzie Bay in 1975. However, Y-O-Y cod were captured at only 2 of 5 sites sampled in the same region in 1974 (Hunter 1979). Griffiths and Buchanan (1982) captured Y-O-Y at 7 of 8 sampling sites about 30 km north of the Mackenzie Delta in 1980 and in 15 of 72 samples (at five sites) in the same area in 1981. Y-O-Y Arctic cod were rare in Tuktoyaktuk Harbour and Kugmallit Bay in mid-summer 1982 (Ratynski 1983).

CENTRAL AND WESTERN CANADIAN ARCTIC ISLANDS

Little sampling has been conducted in this large area (Fig. 4). Most data are from isolated reports. For example, Walters (1953a, b) reported Arctic cod near Prince Patrick Island, and in waters between Victoria Island and the Canadian mainland. Arctic cod were captured in southern Amundsen Gulf in 1961-64 and 1977 by Hunter (1979). In a survey at southeastern Melville Island, Buchanan et al. (1977) captured small numbers of Arctic cod, but polar cod were more abundant. Bain and Sekerak (1978) summarized catch records and SCUBA observations of Arctic cod along the coasts of Bathurst Island, Cornwallis Island, Somerset Island, Boothia Peninsula and Little Cornwallis Island. They found substantial numbers only in two bays along the southern coast of Cornwallis Island and at Creswell Bay, Somerset Island. Green and Steele (1975) also reported Arctic cod in Resolute Bay beneath the ice in December, and Emery (1973) observed Arctic cod beneath the ice nearby. Ross (1835) observed many Arctic cod along the east coast of northern Somerset Island in July 1833.

Feeding studies of fish, seabirds and marine mammals have documented that Arctic cod are present in Barrow Strait (Bradstreet 1977, 1980; this study), and at Prince of Wales (Sekerak, unpublished data), Prince Patrick (Walters 1953b), and Bathurst (Finley 1978) islands.

Although Y-O-Y Arctic cod may occur in much of the area, there are few records. Bain et al. (1977) found Y-O-Y Arctic cod to be the major component of ichthyoplankton in and near

Barrow Strait during June 1976. Y-0-Y Arctic cod have also been found near the Boothia Peninsula (Thomson et al. 1978); in Creswell Bay, Somerset Island, and near Cornwallis Island (Sekerak et al. 1976a); and at Bellot Strait (Dunbar 1947).

CANADIAN EASTERN ARCTIC

Some regions of the eastern Canadian Arctic have been subject to large survey programs of zooplankton or ichthyoplankton in recent years. These have considerably increased information on distribution of Arctic cod, especially Y-0-Y (Fig. 5). Several studies of seabird and marine mammal diets have assessed the role of Arctic cod in food chains. There are few reports, especially in recent years, of Arctic cod (other than Y-0-Y) from fisheries investigations per se.

Jensen (1948) recorded Arctic cod at several locations along the coast of Greenland (Fig. 5). Vladykov (1933) compiled previously unreported Arctic cod collections taken between 1919 and 1930 in the Hudson Bay-Hudson Strait-Ungava Bay region. These records document that Arctic cod occur throughout southern and eastern Hudson Bay. Vladykov (1933) also listed site-specific reports from Hudson Strait and Ungava Bay.

Recent surveys employing large trawls have increased knowledge of Arctic cod in the Ungava Bay-Davis Strait region. In a series of offshore tows in Ungava Bay, eastern Hudson Strait and Davis Strait, MacLaren Marex Inc. (1978) caught Arctic cod in 77 of 94 successful trawls. Arctic cod were rare in southern Davis Strait but common in the other areas sampled. (The above report used the common name 'polar cod' and the scientific name 'Boreogadus saida'. We assume that the common name was applied incorrectly.) Marc Allard (Makivik Corp., Montreal; personal communication) reported B. saida in 22 of 24 bottom trawls in Ungava Bay. In a similar but larger program, Imaqpik Fisheries Inc. (1981) reported polar cod (we again assume them to be B. saida) in 93 of about 110 offshore trawl samples taken throughout Ungava Bay and eastern Hudson Strait.

Site-specific studies have reported Arctic cod from restricted localities. Bohn and McElroy (1976) found considerable numbers of Arctic cod by trawling near northwestern Baffin Island. Small numbers of Arctic cod were observed or captured by SCUBA divers in southern Eclipse Sound (Fabijan 1983), and Arctic cod were present in eastern Pond Inlet in 1979 (Bradstreet 1982). Sekerak (unpublished data) captured small numbers of Arctic cod at southeastern Devon Island in 1976, and observed several small schools in pan ice fields off the island in 1978. Thomson et al. (1979) captured a single Arctic cod near southeastern Devon Island, during a SCUBA survey. Den Beste and McCart (1978) trawled small numbers of Arctic cod from several areas near the mouth and to the northeast of Frobisher Bay. Ellis (1962) reported two dead Arctic cod on the beach in Frobisher Bay in July 1953.

Feeding studies of other vertebrates indicate that Arctic cod are widespread in much of the eastern Arctic, being recorded as prey from northern Hudson Bay east through Hudson Strait and Ungava Bay and then north along the coasts of Baffin, Devon and southeastern Ellesmere islands; they are also known from northern Foxe Basin (e.g., Dunbar and Hildebrand 1952; McLaren 1958; Ellis 1962; Moore and Moore 1974; Mansfield et al. 1975; Bradstreet 1980, 1982; Gaston and Nettleship 1981; Bradstreet and Cross 1982; Finley and Gibb 1982; Finley and Evans 1983).

Extensive surveys have established that Y-0-Y Arctic cod are common in Lancaster Sound (Sekerak et al. 1976b) and northwest Baffin Bay (Sekerak et al. 1979; Sekerak 1982b). Site-specific studies have recorded Y-0-Y at northwestern Baffin Island (Bohn and McElroy 1976); Frobisher Bay (Dunbar 1949); in the mouth of Frobisher Bay and at several sites to the north (Den Beste and McCart 1978); and in upper Frobisher Bay (Grainger 1971). A large-scale survey of the western Davis Strait area found Y-0-Y Arctic cod to be abundant only in the mouth of Hudson Strait (Imperial Oil Ltd et al. 1978).

LABRADOR SEA AND NORTHWEST ATLANTIC

Site-specific reports from the Atlantic region and Labrador Sea consist primarily of scattered incidental findings of Arctic cod. Backus (1951, 1957), Gordon and Backus (1957) and Kendall (1909) reported Arctic cod from along the northern Labrador coast (Fig. 5). Arctic cod have only occasionally been reported from coastal waters of the northwest Atlantic; however, they have been found off Quebec (Vladykov 1945) and New Brunswick (McKenzie 1953).

More extensive surveys in offshore waters have found Arctic cod in the Labrador Sea and the extreme northwest Atlantic, but notably not in intensive commercial fisheries farther south. Lear (1979a) compiled data on Arctic cod from many hundreds of 30 min trawl samples taken in Department of Fisheries and Oceans surveys from 1959-78. These records show Arctic cod to be absent on the Flemish Cap and Nova Scotian Bank, and rare in the Gulf of St. Lawrence and on the southern Grand Bank. They become more common on the northern Grand Bank and northeast Newfoundland Shelf and especially on the Labrador Shelf.

Reports of Y-0-Y Arctic cod from the Labrador Sea and waters to the south are scarce, perhaps due to taxonomic confusion. A number of other cods, especially the Atlantic cod (Gadus morhua) and Greenland cod (Gadus ogac), are more common in the area and samples of unidentified Y-0-Y cod may include several species. In a large survey of young fish along Labrador, Buchanan and Foy (1980) reported Y-0-Y Arctic cod throughout sampling sites in inshore areas of Labrador as well as at some offshore stations.

DISCUSSION

Although large areas of the North American Arctic remain unsampled, current data suggest that Arctic cod are more or less continuously distributed from the northern Bering Sea north and eastward around the continent, among the Arctic Islands, and southward to the Labrador Sea and northwest Atlantic. They have an equally broad distribution in the Russian Arctic and, although sample efforts have been extremely limited, Arctic cod probably occur throughout the Arctic Ocean. For example, Andriashev et al. (1980) presented new information on fish observed from drifting ice stations in several years between 1955 and 1973. They presented data on 13 collections of Arctic cod between 77°42'N and 88°25'N (see Fig. 6). To our knowledge these are the northernmost reports of Arctic cod and they firmly establish the species as being common in the Arctic basin, as well as near land masses.

To date the largest gaps in our knowledge of Arctic cod distribution in North America are the channels among the Canadian Arctic Islands and in gulfs and channels along the mainland of Canada from the Boothia Peninsula to Amundsen Gulf. These regions have never been sampled adequately, although the scattered incidental records suggest that Arctic cod could be common throughout the area. Figure 6 illustrates the general distribution of Arctic cod in the North American Arctic based upon the above review and synthesis of available data.

ABUNDANCE OF ARCTIC COD IN NORTH AMERICAN WATERS

The abundance of Arctic cod is best considered for each of the species' three distinctive behavioural and life-history stages. These are (1) eggs, larvae and Y-O-Y individuals distributed pelagically, (2) juvenile and adult cod in their "dispersed" form of distribution, and (3) juvenile and adult cod in their "concentrated" form of distribution, usually described as dense swarms or schools.

PLANKTONIC STAGES

No information exists on the abundance of Arctic cod in two of its three planktonic forms: eggs and early larvae. Studies yielding abundance data on planktonic Y-O-Y cod have, to date, been conducted in late spring or summer/fall: times when Arctic cod are about 5-40 mm long. Sekerak (1982b) summarized information on density of Y-O-Y cod; little new information has become available since 1982 (Table 1). Relatively low densities have been reported in the Chukchi and Beaufort seas (usually less than 1 Y-O-Y per 100 m^3). Higher densities, 1-10 per 100 m^3, are apparent in Lancaster Sound, Baffin Bay and offshore Labrador. Some of the highest mean densities of Y-O-Y cod are from Labrador where 15-30 Y-O-Y Arctic cod/100 m^3 are not uncommon (Buchanan and Foy 1980). Miller (1979) conducted an acoustic survey, coupled with ground-truthing using a mid-water trawl, off northern Newfoundland and southern Labrador. Trawl samples indicated that acoustic targets were about 80% Y-O-Y Arctic cod ranging in length from 35-64 mm. Up to 111 Y-O-Y per 100 m^3 were recorded off northeastern Newfoundland in fall 1978 (Table 1).

The highest mean density of Y-O-Y recorded was 242 per 100 m^3 in Brentford Bay, Boothia Peninsula (Thomson et al. 1978). Arctic cod were unusually concentrated in surface waters at the time of sampling; indeed, special sampling was initiated because concentrations of Y-O-Y were visible at the surface. Density estimates from Brentford Bay are, therefore, not directly comparable with other values.

Data on abundance of Y-O-Y Arctic cod are probably biased due to differences in sampling gear. The Isaacs-Kidd trawl is accepted as one of the most efficient methods of collecting ichthyoplankton due to its large size and fast towing speed. This sampler has been used in the Chukchi and Beaufort seas and has produced relatively low density estimates (see Sekerak 1982a). Smaller samplers that have been used in the eastern Arctic (plankton nets and Miller samplers) are less efficient than the Isaacs-Kidd trawl. Yet estimates from these samplers are higher than estimates from regions to the west where Isaacs-Kidd trawls have been employed. The apparent increase in abundance of Y-O-Y cod from west to east across the North American Arctic is probably real. Nevertheless, rigorous comparisons of the relative efficiencies of different samplers would be helpful in making existing data more comparable.

JUVENILES AND ADULTS: DISPERSED DISTRIBUTION

Table 2 lists information available on abundance of Arctic cod other than Y-O-Y. Data have been expressed in a wide variety of units ranging from kg/trawl to numbers·m^{-2}. In addition, a variety of trawl sizes and types have been used. These variables make comparisons among studies tenuous. A few investigations are more useful since they covered large geographic areas using the same method. For example, Lowry and Frost (1981) surveyed wide areas of western and northern Alaska, and reported that Arctic cod were most abundant in the northeastern Chukchi Sea (mean of 10.3 fish per trawl), moderately abundant between Point Barrow and Prudhoe Bay (7.8/trawl), and less abundant between Prudhoe Bay and Demarcation Point (1.9/trawl) and in the northern Bering Sea (3.3/trawl). Similarly, Pereyra and Wolotira (1977) reported 0.9 kg of Arctic cod per trawl in the southeastern Chukchi Sea, and only slightly less (0.7 kg/trawl) in the northeastern Bering Sea. To date, trawling in the Bering, Chukchi and western Beaufort seas suggests that catches in the range of 1's or low 10's of cod/30 min bottom trawl are common. The large catches of Fechhelm et al. (1984) in the Chukchi Sea near Point Lay (mean of 276 cod per trawl in 19 trawls) are unusual. Most of these specimens were small, but not Y-O-Y.

A number of recent surveys have assessed waters off Labrador, SE Baffin Island and northern Quebec in terms of potential fisheries. Most catches of Arctic cod in these studies have been low, from <1-2 kg per 30 min trawl. These biomass estimates appear to be equivalent to 10's or low 100's of individual cod. However, Arctic cod are more concentrated in some areas. For example, eight trawls in Ungava Bay averaged 23 kg of cod, probably over 1000 individuals per trawl. Lear's (1979a) 1977-78 study also included some large catches of Arctic cod off northern Labrador. However, large catches were the exception.

Quantitative data on the abundance of Arctic cod in ice-covered waters are almost nonexistent. SCUBA divers observed 0.1-0.5 cod per m^2 in small pressure ridges near the ice edge at the mouth of Pond Inlet in spring 1979 (Bradstreet 1982). The Arctic cod were inhabiting crevices in the pressure ridges. Abundance under smooth ice was very low (0.01 per m^2). Emery (pers. comm. in Bain and Sekerak 1978) estimated that roughly 0.1 cod per m^2 were present beneath smooth ice in Allen Bay, Cornwallis Island, in August. Bain and Sekerak (1978), based on SCUBA work under ice, found few or none at several sites in the central Arctic archipelago. At a site where both the undersurface of the ice and the bottom could be viewed, fewer cod were found on the ice undersurface (n = 1) than on the bottom (n = 9).

JUVENILES AND ADULTS: CONCENTRATED DISTRIBUTION

Where Arctic cod occur in a concentrated manner, numbers range from a few hundred concentrated in ice cracks or along shorelines to large schools involving millions of individuals (Table 3). Many records of Arctic cod concentrations are anecdotal. It is unknown whether "dispersed" individuals come together at certain times to constitute large schools or whether some individuals remain dispersed through time while others form schools as distinct entities.

Concentrations of Arctic cod occur in ice cracks, along shorelines in late summer, and in deep offshore waters (Table 3). The reasons for most such concentrations are poorly known. Some concentrations of cod in ice cracks and along shorelines are almost certainly due to escape responses to predators, as described in a following section on marine mammal feeding, but this is certainly not always the case.

Several ideas have been offered to account for nearshore concentrations of Arctic cod in late summer. Klumov (1937) called the inshore movement a 'pre-spawning migration', a term also used by Craig et al. (1982). However, as Craig et al. pointed out, the designation is perhaps misleading since it suggests a direct connection with spawning requirements; spawning does not take place until mid-winter and is not known to occur in the areas of summer aggregations. Also, Craig et al. and others have found that immature cod are included in the inshore movement. Ponomarenko (1968), Kleinenberg et al. (1964) and others have suggested that annual variations in the regional abundance of Arctic cod are a reflection of year-class strength and have attempted to link this to hydrographic features such as run-off. In the Beaufort Sea, nearshore catches of Arctic cod are generally low except when the marine water mass moves shoreward and replaces the brackish water mass (Moulton et al. 1980; Craig et al. 1982; Griffiths et al. 1983). Craig et al. (1982) found a weak correlation between cod abundance and higher salinities, but not between abundance and temperature. By contrast, Fechhelm et al. (1984) and Craig and Schmidt (1985) observed the opposite pattern at Point Lay; in several instances cod abundance increased as salinities fell.

The inshore movement of Arctic cod in certain areas may also be related to feeding opportunities; they are in peak condition at this time and their stomachs often contain considerable amounts of amphipods and mysids (Craig et al. 1982). Mysids swarm in nearshore waters in certain areas of the Arctic in late summer (Griffiths and Dillinger 1981). The inshore movement of Arctic cod possibly is related to hydrographic features (tides, water mass movements) that concentrate their prey during late summer.

Large concentrations of Arctic cod occur near the bottom in relatively deep water in Ungava Bay, northern Labrador Sea and Davis Strait during late summer (MacLaren Marex Inc. 1978; Lear 1979a). We have plotted numbers of cod caught per 30 min trawl versus depth and temperature data from these two reports (Fig. 7). Spearman rank correlations between numbers and colder temperatures were at least marginally significant, whereas correlations between numbers and increasing depths were not significant. Partial correlations determined from stepwise multiple regression analyses gave similar results. It seems that in offshore areas large concentrations of cod are found in cold waters; frequently such cold waters are found at depth.

Reports of concentrations of Arctic cod in winter are few. Murdoch (1885) reported that natives at Point Barrow caught considerable numbers of Arctic cod in late October and early November in shallow waters. (These might have been the same individuals that were observed as large schools before freeze-up.) Arctic cod were not caught again until early February at which time they were exceedingly abundant in about 30 m of water, but only if ice had formed pressure ridges in the area. Early accounts from Greenland also suggest that Arctic cod concentrate in some fiords in winter (Table 3).

At a drifting station in high latitudes of the East Siberian Sea, Arctic cod were most abundant from November to January but occurred in smaller numbers at least to late March (Andriashev et al. 1980). They were caught or observed in holes drilled in the ice and in natural fissures. Large concentrations were sometimes present. From November to February, they appeared to concentrate close to the surface and might have been attracted to electric lights. As natural light returned, they appeared to descend into deeper water. In February most were caught on baited lines from depths of 5-15 m. In March, best catches were obtained from depths of 10-25 m.

DISCUSSION

Present information documents rather thoroughly that Arctic cod reach their southern limits of distribution in North American waters in the northern Bering Sea near St. Lawrence Island and in the Gulf of St. Lawrence and immediately south of Newfoundland. Y-O-Y Arctic cod appear to be most abundant in the eastern Arctic, especially in inshore waters. Although they do occur in deeper waters, their main zone of abundance is in the upper 50 m (Sekerak 1982b). It is hypothesized that juveniles and adults are also more abundant in the eastern than in the western Arctic (Bering, Chukchi and perhaps much of the Beaufort seas). This is supported by information from surveys using large (but not directly comparable) trawls and hydroacoustic data. Lear (1979a) presented data indicating that abundance of Arctic cod off Canada's east coast varied markedly among years. He suggested that occasional migrations of large schools of Arctic cod from more northern areas were responsible for variations in catches on the Newfoundland-Labrador shelf. This and other observations suggest that variations in abundance may represent temporal as well as geographical differences.

DIET OF YOUNG-OF-THE-YEAR ARCTIC COD

The feeding ecology of juvenile/adult Arctic cod has been the subject of several recent studies (Bain and Sekerak 1978; Lowry and Frost 1981; Bradstreet and Cross 1982; Craig et al. 1982; Fechhelm et al. 1984); however, little information on the diets of young-of-the-year (Y-O-Y) is available. In order to partially address this aspect of the life history of Arctic cod, we analysed food habits of 708 Y-O-Y individuals collected between 1976 and 1981 at various locations in the Canadian Arctic. Principal prey items are identified and differences in prey size selection between Y-O-Y cod collected in different regions are discussed. The diets of Y-O-Y cod are then compared with published information about the diets of larger juvenile/adult cod. To our knowledge the following material is the first report of Y-O-Y Arctic cod diet in North American waters.

MATERIALS AND METHODS

Specimens for diet studies were recovered from formalin-preserved zooplankton or ichthyoplankton samples. Laboratory analysis of diet consisted of microscopic examination (normally up to 75X) of the entire stomach contents with no subsampling. (The stomachs of specimens less than about 10 mm in length are not morphologically differentiated. In these cases, contents of the entire foregut were examined.) Food organisms were enumerated. Where possible copepods were identified to species with adults being further subdivided by sex and immature individuals by copepodite stages. Copepod eggs and nauplii were identified to major group (e.g. calanoid, cyclopoid) and nauplii were further differentiated into three broad size categories (i.e. large >0.4 mm, medium 0.2-0.4 mm, and small <0.2 mm). Other organisms were identified only to major group (e.g. pteropods, amphipods, larvaceans, etc.). General taxonomic aids consulted for various identifications were Sars (1901-18), Wilson (1932), Brodskii (1950) and Vidal (1971).

RESULTS

Over the past decade, samples of Y-O-Y Arctic cod have been collected in six regions of the Canadian Arctic (Table 4). Sampling gear and design have varied widely among regions since the primary goals of the individual studies differed. The data from the studies used in the present analyses were collected from 1976 to 1981, at different times during the open-water season (July through September), from water depths between 0 and 600 m, and from habitats including open-water stations, nearshore areas and ice edges (Table 4, Fig. 8). All of these factors combine to make interpretation of the results difficult. However, some important general patterns in food habits of Y-O-Y Arctic cod have emerged and these are made more significant by the fact that they have occurred over all years and in the different regions sampled.

In this study, we counted the number of individuals of each species and/or group found in each stomach; no measurements of biomass were made. In order to have a common data base, individual counts for each taxon were converted to percentages of the total count for all food taxa, and grand means for each study area were determined; these values were used in all comparisons. The results of the stomach analyses for Y-O-Y Arctic cod by region and station are presented in Appendix 1.

Factors affecting interpretations of Y-O-Y diet

Length of fish in relation to food habits: In studies conducted over the entire open-water season, the possibility arises of size-related differences in food habits (i.e. as the fish grows larger, it consumes larger or different prey items). This could result in a biased interpretation, since a dietary change due to growth of the fish could be ascribed to a regional or within-region difference. To address this problem, seven collections, from three different locations that contained sufficient numbers of fish (approximately 20), were each divided into two size classes. For each of the size groups, the percent of the diet contributed by each food taxon was tabulated. These percentages were compared using the Wilcoxon test. No significant differences in food habits based on fish length (Table 5) were found. Consequently, in subsequent analyses all sizes of Y-O-Y cod were grouped together.

Depth of sample in relation to food habits: A second possible confounding factor was depth-related changes in the food habits of Y-0-Y Arctic cod. Samples were collected from a wide range of depths (from 0 to 600 m). In only one case were sufficient data collected at a single station and date such that the effects of depth on diet could be analysed. These data, from a station in Lancaster Sound sampled on 22 July 1976, showed a marginally significant depth-related difference in the diets of Y-0-Y Arctic cod (Friedman S' = 9.84, d.f. = 3; P = 0.02, Table 6). Calanoid copepods constituted most of the diet of Y-0-Y at all depths; however, copepod eggs constituted 70% and 63% of the diet of cod collected at 10 and 150 m, respectively, but only 43% and 17% of diet of cod collected at 0 and 50 m, respectively. Small calanoid nauplii (<0.2 mm in length) constituted 13% and 14% of the diets of Y-0-Y Arctic cod collected at 0 and 50 m, respectively, but only 6% and 4% of the diet of those cod collected at 50 and 150 m. In addition, three copepodite stages of Calanus glacialis were present in the diets of Y-0-Y Arctic cod collected at 0 and 50 m, but were absent from the diets of those collected at 10 and 150 m.

One possible interpretation of these results is that Y-0-Y Arctic cod simply consume what is available at each depth. However, a comparison of the composition of cod diet with the food available revealed some discrepancies. Sekerak et al. (1976b) collected data on zooplankton abundance at the same place and time as that in which the Y-0-Y cod were collected. Pseudocalanus minutus were present in the diets of Y-0-Y Arctic cod from all four depths sampled, but none were found in the corresponding zooplankton samples. Calanus glacialis and Calanus hyperboreus were present in the diets of Y-0-Y Arctic cod from only the 0 and 50 m depths and from the 0 m depth, respectively. However, both species were found in zooplankton samples from all depths. A possible interpretation is that Y-0-Y Arctic cod may not feed only at the depth of their capture.

Nevertheless, despite the depth-related differences observed, smaller copepod life stages (i.e., copepodites, nauplii and eggs) constituted the majority of the diet items at all depths sampled (100% at 0 m, 98% at 10 m, 95% at 50 m and 100% at 150 m; Table 6).

Date of sampling in relation to food habits: Samples collected near Cape Warrender, Devon Island, from 24 July to 7 September 1976 were analysed to determine if date of sampling had any effect on the diet of Y-0-Y Arctic cod. We found no significant relationship (Friedman S' = 1.88, d.f. = 4, P>0.7, Table 7) between the percent composition of various food taxa and date of sampling; however, it should be noted that not all of the samples were collected at the same water depth (Table 8). Although similar groups and species were present in the diets on each sampling date, there were some temporal patterns. Early in the season (3 August), calanoid copepod eggs made up 27% of the diet, but thereafter their contribution to the diet decreased. Copepod eggs were not found in cod during the last two sampling periods (27 August, 7 September; Table 8). It appeared that the early-season abundance of copepod eggs declined as they developed into later life stages. This agrees with the known life history patterns for Arctic copepods (Sekerak et al. 1979). Calanoid naupliar stages were present in the diets throughout the season in varying quantities, which would be expected since these life stages are known to be continuously present throughout the open-water season (Sekerak et al. 1979). Typically, larger copepodite stages and adult forms of most copepods did not appear in the diets until the later sampling periods (27 August, 7 September). It appeared that as the season progressed, both the cod and their prey grew, so that by the end of the season Arctic cod were consuming the larger copepodite stages and adult copepods (Table 7).

Dietary patterns within regions

The results of the stomach analyses for each of the six regions studied (Labrador Sea, northwest Baffin Bay, Lancaster Sound, Brentford Bay, Wellington Channel and the southeastern Beaufort Sea) are presented below and the general patterns observed in the diets of Y-0-Y Arctic cod are then discussed.

Labrador Sea (1979): Table 9 summarizes the analyses of 207 Y-0-Y Arctic cod stomachs collected in the Labrador Sea in 1979 by Buchanan and Foy (1980). Copepods were by far the dominant food items consumed, averaging 95.7% of the diets. Although nine species of copepods were identified, only four (Oithona similis, Calanus glacialis, Pseudocalanus minutus, and Calanus finmarchicus) were major contributors to the diet (Table 9).

Sizes of items constituting the major (>5%) components of Y-0-Y cod diets are given in Table 10. Copepod eggs, nauplii and copepodite stages were the major contributors; adult copepods, although present, were minor components of the diets, at least in terms of numbers. Cyclopoid copepod eggs (0.08 mm diameter) were, on average, the dominant food items (33%), while calanoid eggs (0.16 mm in diameter) contributed only 6%. However, calanoid nauplii (<0.2 to 0.4+ mm) together constituted significant amounts (25%) of the diets. Of the identified copepods, various copepodite stages predominated (length range: 0.25 to 2.0 mm) and adults were rare (Table 10). These results suggest that Y-0-Y Arctic cod selected small prey items up to a maximum of 3 mm in size.

Northwest Baffin Bay (1978): Table 9 summarizes our analyses of the diets of 86 Y-0-Y Arctic cod originally collected in northwest Baffin Bay in 1978 by Sekerak et al. (1979). As in the Labrador Sea, copepods constituted the highest percentage of the stomach contents (86%) with unidentified calanoid copepods being the major contributor (44%). Eight copepod species were identified. Of these, three species (i.e. Pseudocalanus minutus, Oithona similis, and Calanus glacialis) were major contributors to the diets (Table 9). Larvaceans were also significant contributors to the diet (11%), suggesting that Y-0-Y Arctic cod can select alternate food sources if they are locally abundant.

The major components (>5%) of Arctic cod diets were small food items (0.08 to 3 mm in length) (Table 10). Calanoid nauplii (three size classes combined) represented the largest percentage (25.3%) of food items in Arctic cod diets, followed by calanoid eggs (18.8%). Identified copepods were mostly copepodites; adults were rare.

Lancaster Sound (1976): Table 9 summarizes the analyses of 216 Y-O-Y Arctic cod collected in Lancaster Sound in 1976 by Sekerak et al. (1976b). Copepods were again the major contributor to the diet (90%). Most were unidentified early stages of calanoid and cyclopoid copepods. Nine copepod species were identified, and three (*Oithona similis*, *Pseudocalanus minutus* and *Calanus glacialis*) contributed significantly to the diets. Larvaceans were also a significant component (4%). The diatom *Coscinodiscus* sp. was relatively abundant in the diets, averaging 4% (Table 9).

As in the Labrador Sea and northwest Baffin Bay, smaller copepod life stages (i.e., eggs, nauplii and copepodites) formed the bulk of the copepod component of Y-O-Y Arctic cod diets (Table 10). Calanoid eggs and nauplii stages (63%) were the most abundant prey items. Of the identified copepods, few adults were found; almost all were various copepodite stages (size range: 0.25 to 3 mm in length), which again suggested that Y-O-Y Arctic cod consumed relatively small prey items.

Brentford Bay (1977): Table 9 summarizes the analyses of 38 Y-O-Y Arctic cod collected in 1977 in surface waters of Brentford Bay, northeast Boothia Peninsula, by Thomson et al. (1978). Copepods represented almost 100% of diet items. Of the seven copepod species identified, only two *Calanus glacialis* (42%) and *Acartia longiremis* (27%) contributed significantly to the diets. Unidentified calanoid copepods (21%) were also major contributors. Smaller forms (copepodites and nauplii) were again the dominant food items in the diets of Y-O-Y from Brentford Bay; adult copepods were rare (Table 10).

Wellington Channel (1976): Table 9 summarizes the analyses of 62 Y-O-Y Arctic cod collected near the Wellington Channel ice edge in 1976 by Bain et al. (1977). As in other regions, copepods dominated the diet (98% of total items). Unidentified calanoid copepods were the major items consumed (70%). Only one identified species, *Pseudocalanus minutus*, was a major dietary item (20%) (Table 8).

The lengths of copepods in the diet ranged from 0.08 to 2 mm (Table 10). This was slightly smaller than the range observed in other regions and may have been due to the smaller size of Arctic cod in this collection (mean 9.2 mm) than elsewhere (overall mean 18.3 mm). This suggested that Y-O-Y Arctic cod consumed prey in direct relation to their size; in contrast to findings above concerning the length of fish in relation to food habits. In this case, the smallest Arctic cod consumed the smallest prey.

Southeastern Beaufort Sea (1981): Table 9 summarizes the analyses of 99 Y-O-Y Arctic cod collected in the southeastern Beaufort Sea during 1981 by Griffiths and Buchanan (1982). Copepods represented over 99% of the food items consumed, with unidentified calanoid nauplii and eggs being the dominant contributors (Table 9). Of the identified copepod species, only *Pseudocalanus minutus* contributed significantly to cod diets.

Sizes of major food items are summarized in Table 10. Calanoid copepod eggs (0.16 mm in diameter) and nauplii (<0.2 to 0.4+ mm in length) constituted most of the diet. Of the identified copepods, *Pseudocalanus minutus* copepodites I/II (0.25 mm in diameter) were major dietary components. Adult copepods, although present, rarely contributed significantly to the diet.

General patterns among regions: To compare the six different regions, data from all sampling dates and depths within each region were combined (Table 11). It is clear that copepods constituted the major portion of the diet in each region, representing from 86 to 99.9% of the food items consumed. In four regions, calanoid copepod eggs and naupliar stages formed the bulk of the copepod component of the diet and of the total diet (Fig. 9). Copepodite stages of the calanoid copepods *Pseudocalanus minutus* and *Calanus glacialis* and the cyclopoid copepod *Oithona similis* occurred in all six regions; however, only *Pseudocalanus minutus* (copepodites and, rarely, the adults) contributed significantly to the diets in all six regions. Although several copepod groups or species were common to all regions, dominant groups or species of copepod varied within region, by sampling date and depth, and among regions. This suggests that Y-O-Y Arctic cod typically feed on the groups and species that are locally abundant, and are not limited to particular groups or species.

The main point of interest in these results is that, even though the samples were collected over a number of years (1976-1981), at a variety of depths (0-600 m), and at different times over the open-water season (June-September), there was a surprising degree of consistency in the composition of the diets of Y-O-Y Arctic cod in the six regions.

The small contribution or near absence of phytoplankton in the diets of Y-O-Y Arctic cod is surprising because of the small size (9.2 to 20.3 mm) of the individual fish and consequently the restriction in the size of prey they can consume. However, it appears that Y-O-Y Arctic cod are able to feed on the smaller life stages of copepods (i.e., copepodites, nauplii, eggs; 0.08 to 3 mm in length), food of much higher caloric value than equivalent weights of phytoplankton. The small size of the mouth opening of Y-O-Y Arctic cod may explain the absence of large amphipods, a food item commonly consumed by larger Arctic cod.

DISCUSSION

Most studies of the feeding ecology of Arctic cod have dealt primarily with juvenile and adult individuals. Table 12 compares the diets of larger Arctic cod collected from across the North American Arctic with diets of Y-0-Y as determined in the present study. In general, larger Arctic cod consumed copepods, amphipods, mysids and fish, with lesser contributions from euphausiids, larvaceans, cumaceans, chaetognaths and pteropods. Despite differences in the sizes of Arctic cod in the various studies, the importance of zooplankton, particularly copepods, has been consistently demonstrated (Table 12). The major dietary difference between juvenile/adult and Y-0-Y Arctic cod was that Y-0-Y cod consumed the small copepod life stages (eggs, nauplii and copepodites; usually less than 3 mm in length) almost exclusively, while juvenile/adult Arctic cod fed on adult copepods and other larger organisms (e.g. amphipods, mysids, fish, etc.). Ponomarenko (1968) also found that cod larvae and fry feed on copepod eggs, nauplii and copepodites. Lowry and Frost (1981) reported size-related differences in food habits of juvenile/adult Arctic cod in the northern Bering Sea. Gammarid amphipods and shrimp were common in large cod but were much less commonly eaten by smaller individuals. Similarly, Bain and Sekerak (1978) found mainly copepods in the stomachs of Arctic cod <100 mm in length and larger items (e.g. amphipods) in the stomachs of cod >100 mm in length. Bohn and McElroy (1976) also reported that small Arctic cod (<100 mm in length) ate proportionately more copepods than did large cod (>100 mm), which consumed proportionately more amphipods. It is clear from the information provided in the present study that Y-0-Y Arctic cod begin by feeding on smallest copepod life stages and that as the cod increase in size, the size of their prey also increases. This pattern can be expected since fish typically feed on the largest prey they are physically able to ingest. However, it should be noted that Arctic cod will also feed extensively on locally abundant prey items. It is not uncommon to find juvenile/adult cod that have consumed large quantities of small prey items.

METHODOLOGICAL CONSIDERATIONS IN THE USE OF SCALES AND OTOLITHS FOR AGEING AND MEASURING GROWTH OF ARCTIC COD

As shown above, the Arctic cod is a widespread and sometimes abundant fish in marine waters of the North American Arctic. The Arctic cod is the major food source of most of the marine mammals and many of the seabirds inhabiting northern areas and it is through Arctic cod that most energy is transferred to higher vertebrates. For many consumers, there is no adequate, alternative food supply to Arctic cod.

Given the ecological importance of Arctic cod, it is imperative to understand as much as possible about the population dynamics of this fish. However, our present understanding of Arctic cod biology is almost totally limited to opportunistic sampling during inshore movements in late summer and to more systematic sampling of planktonic Y-0-Y individuals that are still too small to be important in the diets of higher vertebrates. Given the logistic, cost and technical constraints of extensive year-round studies of Arctic cod in northern environments, alternative sampling approaches are required. One such approach involves using the Arctic cod's natural predators as sampling gear. These predators are well adapted for capturing cod, and in many cases are probably more effective samplers than any gear type that man can devise. Many of these predators are regularly harvested by northern residents over extensive geographic areas and during every season of the year.

First we consider the use of scales for age determination. Then, we address certain methodological questions affecting the use of otoliths in determining the age of Arctic cod and estimating growth: are the concentric rings that are visible on otoliths annular marks and, if so, when are they deposited? Can otoliths be used to determine the age of fish reliably and, if so, which ageing methods are appropriate? What measurement techniques are most appropriate? Are within- and among-observer errors in ageing and measurement techniques acceptable? And, can growth of Arctic cod be estimated reliably from measurements of annular marks?

AGEING FROM SCALES

The use of gadid scales for age determination has not met with general success due to difficulty in the identification of annular rings, especially in older fish (Chilton and Beamish 1982). Nevertheless, determination of the usefulness of Arctic cod scales for ageing purposes was thought to be warranted since scales are sometimes more conveniently collected (and, if useful, less time-consuming to interpret) than are otoliths.

Scales were taken from the area between the second dorsal fin and the lateral line of two Arctic cod, 134 and 151 mm long. All scales examined were small and roughly circular, about 0.6 mm in diameter. Circular ridges were readily visible on scales and were oriented around a common focus. Each circular ridge was composed of short lengths of a raised substance, hyalodentine according to Lagler (1956), separated by a short distance from similar material. This gave the appearance of a circular dashed line. In some species of fish these ridges, or rings, are heavy and widely spaced if laid down when growth was rapid, but fine and close together if laid down during periods of slow growth. The alternating pattern of widely-spaced and finely-spaced rings is used to age the fish, with each series of finely-spaced rings being interpreted as an annular mark. Eight and ten circular rings were evident on scales from the 134 and 151 mm Arctic cod, respectively. Because circular rings were about equidistant from each other, it was not possible to discern annular marks. Moreover, the relatively small number of circular rings on the scales of Arctic cod prohibits their use for ageing since growth patterns are readily recognizable only if such rings are numerous. For example, over 20 circular rings are evident between the focus and the first annular ring in photographs of Pacific cod (Gadus macrocephalus) scales (Chilton and Beamish 1982: 24-25). The Arctic cod from which scales were obtained were two or three years of age according to age-length data presented in this report. Pacific cod of similar age would have at least 30-40 circular rings on their scales, compared to the 8-10 evident on Arctic cod scales.

In summary, scales from Arctic cod appear to be inappropriate structures for ageing these fish. Thus we investigated the use of sagittal otoliths for age determination.

OTOLITH AGEING TECHNIQUES

Otoliths are bony plates in the inner ear of teleost fish. Since these structures often accumulate in predator stomachs, where they are largely resistant to digestion, collection of stomach or fecal samples from vertebrates that have eaten Arctic cod usually results in the collection of Arctic cod otoliths. Sometimes the numbers of otoliths are very large; up to 2900 otoliths have been found in a single white whale stomach.

There are three pairs of otoliths in the inner ear of a fish; the largest pair, or sagittae, are frequently used for age determination (Tesch 1971). In this study, sagittal otoliths were examined using binocular dissecting microscopes and various lighting techniques. We usually illuminated the otolith surface with reflected red light (directed obliquely from above). Otoliths were placed on a black background and submerged in glycerin for viewing. This viewing method decreased glare, and provided better contrast at the otolith's edge and between hyaline (translucent) and opaque layers than did methods involving any combination of reflected white light, transmitted white light, clear background, white background or dry otoliths. In ageing otoliths that had been broken and burned (see below), reflected white light was used.

Large numbers of Arctic cod otoliths were aged in this study (Table 13). In many cases we subsampled from the large number of otoliths present in a predator's stomach; in such cases 25 otoliths were randomly chosen. After otoliths were removed from their original sample containers, they were placed in 96-well microtest plates in a 3 part glycerin : 1 part 75% ethanol solution. After analysis of the otoliths, microtest plates were sealed for permanent storage.

Given the large numbers of otoliths aged, it was necessary to employ ageing techniques that were not only accurate, but rapid. We tested three techniques (external viewing of lateral convex surface, grinding, and burning) for their accuracy one-to-another, and also tested within- and among-observer variability in the external viewing technique.

Otoliths used for the examination of three ageing techniques were taken from white whale stomachs collected during September 1978. Whole otoliths (n = 294) were initially examined by viewing the external surface with transmitted light. Ages were evaluated independently by two experienced observers who then discussed their results. In 255 cases an assigned age was agreed upon; in the 39 cases where ages were not agreed upon the otoliths were eliminated from further analysis.

The 255 'known-age' otoliths were divided into two groups for further treatment. The lateral surfaces of 134 otoliths were ground by hand using a fine sharpening stone. Ground otoliths were then rinsed with glycerin and viewed. The remaining 121 otoliths were sectioned through the nucleus, perpendicular to the long axis of the centrum, with shears. The broken surface was gently burned in a very low flame of an alcohol burner for 5-10 s. The halves were mounted in plasticine, broken surface upwards, and viewed. All secondary age determinations were made by a single observer, who had previously participated in assigning the primary age.

Otolith ages determined by grinding or burning did not differ markedly from those determined by external viewing (Table 14, sign test $P>0.05$). (Given the large number of statistical tests performed in this study, an alpha level of 0.01 was chosen to represent statistical significance.)

We chose determinations of age from external viewing as the preferred technique because it was rapid and showed no difference in precision than the more time-consuming methods (grinding, burning). It should be kept in mind, however, that the age determinations of some older fish otoliths made by external viewing are, on average, underestimates of one year when compared to values obtained by grinding or burning techniques (Table 14).

Preferred ageing technique

Whole otoliths were aged by viewing the exterior, lateral, convex surface. Age was determined by counting the number of complete translucent (hyaline) layers. The outer hyaline layer was defined as complete if it was present around more than 75% of the otolith's edge. In addition, for very small otoliths the hyaline layer had to be detached from the centrum to be classified as an annular ring. In small sectors of some otoliths, successive hyaline layers tended to blend together. If, in such cases, hyaline layers were clearly visible elsewhere on the otolith, annular rings were counted, even though some individual hyaline layers may not have been clearly visible around more than 75% of the otolith's edge. Age-frequency distributions for all Arctic cod otoliths taken from predators and used in this study are given in Appendix 2.

Observer variability in otolith ageing

In three separate trials, three observers each independently determined the ages of 100 otoliths chosen from ringed seal stomachs or whole Arctic cod. Otoliths were randomly ordered for each trial to reduce the possibility of individual otolith recognition, or memorization of age sequences. Observers did not compare their results. Within-observer variability in the ages assigned during the three trials was not significant (Table 15; all Friedman S' probabilities >0.01). This means that there was no trend over time in the ages assigned. However, there were significant differences among observers in both the mean difference in ages determined during the three trials (P<0.001) and in the difference between the maximum age and minimum age made in these determinations (P<0.001). Thus, some observers were more consistent than others in the age assigned to a given otolith.

Therefore, all otoliths used in this study were aged independently by two observers. Results were compared and otoliths for which there was disagreement in age were discarded. This approach led to high level of reliability.

Otolith readability and abrasion

Observer confidence in each age determination was classified on a five point scale as follows:

0. Otolith easy to age; annular rings distinct at all measurement points (see below).
1. Otolith easy to age; observer has high confidence that second observer would record the same age; most annular rings distinct at measurement points but in some cases the annulus is not distinct or present. In these cases the position of the measurement point could be accurately determined by extrapolating from adjacent parts of the annular ring.
2. Otolith less easily aged; observer has confidence that he/she would assign the same age to this otolith on a second reading but not confident that second observer would record the same age; measurements of annular rings as above.
3. Otolith difficult to age; observer not confident that he/she would assign the same age to this otolith on a second reading; annular rings unclear or not present at measurement points. Not possible to determine the precise measurement point.
4. Otolith very difficult or impossible to age; very low observer confidence in age assigned; annular rings unclear and cannot be measured.

Otoliths could be difficult to age for any of several reasons. In some cases, the otoliths were naturally opaque, or showed many narrow hyaline layers that made it difficult or impossible to determine the actual numbers or positions of annular rings. In a few cases it appeared that abnormally-shaped or transparent otoliths were naturally malformed.

In addition to recording the 'readability' of each otolith, an assessment of each otolith's physical condition was also made and classified on a four point scale as follows:

1. Otolith not abraded; apparently in perfect condition.
2. Otolith slightly abraded; abrasion without effect on reliability of age determination.
3. Otolith moderately abraded; abrasion potentially affecting the reliability of age determination.
4. Otolith very abraded or broken; age determinations not reliable.

Abrasion of otoliths occurred for two main reasons: digestion, or storage in formalin. Otoliths digested within predator stomachs became progressively transparent from the surface inwards. Such otoliths were more susceptible to damage along their outer edges than were unabraded otoliths. Otoliths stored in formalin were more transparent over a greater percentage of the otolith's surface than were digested otoliths. Otoliths that had been stored in formalin for long periods were not used.

Readability and abrasion values for all otoliths taken from predator samples and aged in this study are given in Appendix 3.

Hyaline layer (annular ring) formation in Arctic cod otoliths

Since Arctic cod scales are very small and annular rings are not easily identified (see above), North American workers (Bain and Sekerak 1978; Wells 1980; Craig et al. 1982) have used otoliths to estimate fish age. Arctic cod are apparently short-lived but relatively fast growing. Fish older than five years are uncommon in most collections. Hyaline layers, which have been generally accepted as annual marks, are readily apparent in most otoliths. Perhaps due to the apparent good 'readability' of Arctic cod otoliths, little or no effort has been expended in verifying the accuracy of age determinations, even though Chilton and Beamish (1982) and Beamish and McFarlane (1983) have stressed the importance of verifying ages and critically examining ageing techniques at every opportunity.

The validity of using hyaline layers as annual marks in Arctic cod cannot be determined directly in this study. Direct validation requires that fish of known age (usually raised in captivity or taken in mark-recapture studies) be examined to document the presence and number of hyaline layers. Nevertheless, we have indirectly validated the ageing technique used in this study by examining the patterns of hyaline and opaque layer formation in cod otoliths collected over a continuous twelve month period.

In most fish species, hyaline layers are laid down during periods of slow or no growth, which in northern areas occurs during winter and spring (Tesch 1971). Opaque layers are laid down during periods of rapid growth. In some species, the timing of hyaline layer deposition varies a good deal from fish to fish and, generally speaking, the older the fish, the later the hyaline layers are deposited (Tesch 1971).

We examined patterns of hyaline layer deposition in Arctic cod otoliths taken from ringed seal stomachs and feces collected over 12 months at Pond Inlet, beginning in June 1978. For most months there were three age-cohorts with useful sample sizes (n $\geq$15). The fish in the 1977 cohort were 1+ years old when first sampled in June 1978 and 2+ years old when sampled in May 1979. Similar values for the 1976 and 1975 cohorts were 2+ and 3+, and 3+ and 4+, respectively.

As expected, hyaline layers were deposited in most otoliths during the winter months, although in older fish deposition began and peaked later than in younger fish (Fig. 10).

We also measured the thickness of any opaque layer distal to the outermost hyaline layer along a line running through the long axis of the centrum. In the 1977 and 1976 cohorts, there were clear patterns of increasing deposition with time for either the younger or older age classes (Table 16). In the 1975 cohort, this pattern generally held true for the 3+ age class until December. Sample sizes from January to May 1979 were very small because hyaline layers were being deposited on most otoliths during this period, but it seemed that in at least a few 3+ fish the fourth hyaline layer had still not been deposited by May 1979.

Taken together, the pattern of hyaline layer deposition and the pattern of growth in opaque material distal to the outer growth ring provide strong evidence that the hyaline layer is, in fact, an annual mark. In three cohorts, thickness of hyaline material peaked but once a year, and in each age group the thickness of opaque material increased with time. The amount of opaque material deposited was greatest just before the annular ring was formed and least just after. We are confident that the number of hyaline layers on an Arctic cod otolith is an accurate estimate of fish age.

OTOLITH MEASUREMENT TECHNIQUES

Otolith measurements were made to the nearest 0.1 mm using occular graticules calibrated with a stage micrometer (50 mm scale with 0.1 mm graduations). When both otoliths from a fish were present (paired otoliths were available from whole cod collections), the right otolith was measured.

Several types of otolith measurements were made during this study (Fig. 11). Length and width measurements were made along lines that passed through the centre of the centrum and were oriented perpendicular to the otolith's ends or sides, respectively. Total length and width were defined as the maximum lengths of such lines. Three of four measurements of annual growth in otoliths (i.e. from the centre of the centrum towards the anterior, posterior or ventral edges) were made in a similar fashion, except that measurements were from the centre of the centrum to the beginning of successive hyaline layers. The fourth (length) measurement of annual growth was from the beginning of successive hyaline layers on the anterior end of the otolith, through the centre of the centrum to the beginning of the matching layer on the posterior end. This measure of annual otolith growth was called the 'ring-to-ring' measurement. Centrum diameter was measured along a line perpendicular to the anterior and posterior ends of the otolith and passed through the centrum's centre.

Observer variability in otolith measurements

We tested within- and between-observer variability in three measurements of annual growth in Arctic cod otoliths (centrum-anterior, centrum-posterior and ring-to-ring). Otoliths with good readability (coded as zero) were chosen from four predators: ringed seals, bearded seals, white whales and narwhals. In three separate trials, two observers each independently aged and measured each otolith. The following data were recorded: age, abrasion, total otolith length, total otolith width, centrum diameter, distance from the centre of the centrum to the anterior end of the otolith, distance from the centre of the centrum to the posterior end of the otolith, and the three measurements of annual growth at each annular ring. For 0+ fish, no annular ring measurements were made.

Only those otoliths determined to be the same age by each observer in every trial were used in the analysis of measurement variability.

Estimated variability in each observer's measurements of each centrum-anterior annular ring was computed as follows:

$$\frac{|L_1-L_2| + |L_1-L_3| + |L_2-L_3|}{\text{cen-}L_1 + \text{cen-}L_2 + \text{cen-}L_3}$$

where L_1-L_3 were the centrum-anterior measurements of a particular ring on trials 1 to 3, respectively, and $\text{cen-}L_{1-3}$ were the measurements of the distances from the centre of the centrum to the anterior end of the otolith on trials 1 to 3, respectively. Estimates of variability were also computed for each observer's centrum-posterior and ring-to-ring measurements. In the latter case, measurements of total otolith lengths on trials 1 to 3 were used in the denominator of the above equation.

There were no significant between-observer differences in measurements of annular rings in Arctic cod otoliths (Table 17). Use of the above equation, whose denominator standardizes for differing feature sizes, permitted a direct comparison of the precision of the three methods. Ring-to-ring measurements were the least variable of the three methods.

Centrum-ventral versus ring-to-ring measurements

In several previous studies, measurements of otolith growth have been made along otolith radii (usually along the centrum-ventral edge radius). There were two major limitations to such an approach in the present study. Arctic cod otoliths are small in comparison to those of many of the commercial species for which the measurement-along-radii methods have been developed. This results in annular growth rings being crowded along the centrum-ventral edge radius in this species. Furthermore, the limitations of the optical equipment used in the present study meant that measurements of otoliths were only accurate within plus-or-minus 0.1 mm. We compared ring-to-ring versus centrum-ventral measurements by choosing 20 otoliths of each of five age classes (1+ to 5+) and measuring annular rings on each otolith using the two methods (Table 18).

Differences in length between adjacent age classes (defined as the mean length of the older class minus the mean length of the younger class expressed as a percentage of the older class mean length) were consistently greater for ring-to-ring measurements than for centrum-ventral measurements. Given the level of precision attainable with the optical equipment used in this study, it was important to measure otolith characteristics that gave relatively large differences between adjacent age classes. Differences between mean otolith lengths at adjacent year class marks were significant for all ring-to-ring measurements (all t-test $P<0.01$) but for only three of the four centrum-ventral measurements (not significant for the 5+ vs 4+ comparison). The comparisons indicated that ring-to-ring measurements were more likely to detect differences in otolith lengths-at-age than were centrum-ventral measurements. We chose the former as the preferred measurement technique.

GROWTH OF ARCTIC COD OTOLITHS

Large numbers of Arctic cod otoliths were available from many different areas in several different years. One of our objectives was to compare differences in otolith growth from year-to-year or area-to-area based on measurements of successive annular rings using the ring-to-ring measurement method. This required validation of the premise that, in a given population of Arctic cod, measurements of the annular ring laid down in year x would be the same in year x, x+1, x+2, etc.

We took a conservative approach in defining a population of cod. Fish caught in the same area at the same time of year, either by predators or biologists, were defined as a population. In four cases, one population was sampled in two successive years (Table 19). The lesser of either all otoliths with good readability (coded as 0), or a randomly-selected group of 100 of those otoliths, was chosen for analysis. Each otolith was aged independently by two observers; when observers disagreed on otolith age it was discarded and an otolith of similar total length was chosen to replace it. Total otolith length and ring-to-ring measurements at each annulus were made by one observer.

In 10 cases (i.e. location-fish age combinations) independent comparisons could be made of the same annular ring measured in successive years (Table 20). In seven of 10 cases, t-tests showed no significant difference. In three cases there were significant differences, twice in one direction and once in the other. When results from the 10 independent tests were combined using the Winer method (Rosenthal 1978), the overall probability ($z = -1.92$) was not significant ($P>0.05$). Thus it seemed feasible to reliably estimate the length of an otolith in previous years based on ring-to-ring measurements of annular rings.

AGE-FREQUENCY DISTRIBUTIONS OF ARCTIC COD OTOLITHS IN PREDATOR SAMPLES AND SELECTED FISH COLLECTIONS

Variability in the relative abundance of different-aged Arctic cod is of obvious importance to the population dynamics of the cod themselves and of great relevance to the biology of dependent predators. Many predators are heavily dependent on certain-sized (and hence certain-aged) cod during some seasons of the year (see below). If the numbers of appropriately-sized (and -aged) Arctic cod vary from year to year or place to place, many vertebrates valued by man might need to find alternative food when cod in predators' preferred size ranges (and hence year classes) are in short supply. Analyses of the year class strength of Arctic cod have not previously been attempted. In this study, by using the otoliths found in stomach or fecal samples from cod predators, we have been able to make many comparisons of the age-frequency distributions of Arctic cod otoliths. This has provided data both on characteristics of Arctic cod populations and on variability in predator diet.

Careful selection of predator samples has permitted us to control for possible seasonal, annual and location effects. Statistical comparisons of frequency distributions were made with Kolmogorov-Smirnov tests using the numbers of predator samples (or occasionally the numbers of fish collections) rather than the number of otoliths as the sample sizes. This was a conservative approach. Tests followed procedures in Hollander and Wolfe (1973) when the larger n was ≤ 20, and those in Conover (1971) when the larger n was >20.

AGE-FREQUENCY DISTRIBUTIONS OF ARCTIC COD OTOLITHS IN RINGED SEAL SAMPLES

Many Arctic cod otoliths were available from ringed seal stomachs or feces. We subsampled the available material and compared age-frequency distributions among age classes of ringed seals, seasons, locations and years. Ringed seals were aged by counting dentinal annuli as described by McLaren (1958) and Smith (1973) and four age classes were subsequently recognized: 0+ age seals (less than one year old); juvenile seals (1+ to 3+ years); immature seals (females 4+ to 5+ years old, males 4+ to 6+ years); and adults (females 6+ years or older, males 7+ years or older). Similarly, ringed seal samples were grouped into four seasons that reflect changing ice conditions at two high arctic locations (Pond Inlet and Grise Fiord): haul out (June-July), open water (August-October), early winter (November-January) and late winter (February-May). Ringed seal samples from Labrador in 1979 were grouped into two seasons (haul out and open water) depending on whether they were collected before or after 19 May, the date when fast ice broke up near Makkovik in 1979 (R. Buchanan, LGL Ltd., pers. comm.).

We found no evidence that the age distribution of Arctic cod in ringed seal stomachs was affected by: habitat, viz nearshore vs. offshore (Fig. 12); amount of food in stomach (Fig. 13); age of seal (Fig. 14); season or year of collection (Fig. 15); or collection area (Fig. 16).

This lack of significance provided some justification for pooling samples into larger groupings, which permitted examination of more general effects of season and location. Samples from three areas near Pond Inlet (village, Kounuk, ice edge), and from Grise Fiord, Resolute and Labrador were used in these more general analyses.

Seasonal effects--grouped samples

There were no significant differences in the age-frequency distributions of Arctic cod otoliths taken from ringed seals collected during different seasons at Grise Fiord (Fig. 17, Kolmogorov-Smirnov $P>0.1$ in six comparisons). At Pond Inlet, however, one of the six seasonal comparisons was significant (late winter versus open water, $P<0.01$). The five other comparisons were not significant (all $P>0.1$). All late winter samples at Pond Inlet were from the ice edge bordering Baffin Bay, whereas all open-water samples were from protected channels, either near the village of Pond Inlet or near Kounuk. Thus, the apparent seasonal effect could have been partly an area effect. Given the lack of seasonal effects at Grise Fiord and the absence of within-subarea seasonal effects at Pond Inlet ($P>0.1$ in five comparisons; Fig. 15), the single 'seasonal' effect at Pond was probably an artifact.

Area effects--grouped samples

There were no significant differences in the age-frequency distributions of cod otoliths taken from ringed seals collected in protected waters near the village of Pond Inlet versus near Kounuk (Fig. 18, $P>0.1$). There was, however, a significant difference in age distributions from samples taken at the ice edge versus Kounuk ($P<0.01$) and a marginally significant difference between the ice edge and village samples ($P = 0.02$). On average, cod at the ice edge were older than those represented by otoliths from protected waters. Thus cod at the ice edge may have had a different age structure than cod in the protected channels. Samples from the village and from Kounuk were combined based on the similarity of their age-frequency distributions, and compared with other areas: Pond--ice edge, Grise Fiord, Labrador and Resolute. In six of ten possible comparisons, significant differences among areas were found (all $P<0.01$). In two additional comparisons (Pond--village/Kounuk vs Resolute; Grise vs Resolute), differences were marginally significant ($P = 0.02$). In only two comparisons (Pond--ice edge vs Grise; Labrador vs Resolute) were there no significant differences ($P>0.05$). The implication of these results is that there is considerable location-related variability in the age-frequency distributions of Arctic cod otoliths found in ringed seal samples.

AGE-FREQUENCY DISTRIBUTIONS OF ARCTIC COD OTOLITHS IN OTHER MARINE MAMMAL SAMPLES

We also looked for differences in the age-frequency distributions of Arctic cod otoliths in samples from bearded seals, harp seals, narwhals and white whales (Fig. 19-21). We again controlled for potentially significant confounding factors when trying to isolate the effects of a single factor. When harp seal, narwhal and white whale data were considered, there were no significant differences in the age-frequency distributions of cod otoliths in any of the three comparisons involving location, the two comparisons involving age, the two comparisons involving year, or the single comparison involving season (all $P>0.1$). In one comparison where location and year effects could not be separated (white whale data), there was also no significant difference ($P>0.1$), although mean ages were quite different. When bearded seal data were analyzed, only the effects of location could be considered. There were no differences in the age-frequency distributions of otoliths in three areas ($P>0.1$ for comparisons among Grise, Pond and Clyde), but differences between each of these three areas and Labrador were marginally significant ($0.02<P<0.1$) despite small sample sizes. Many of the otoliths present in samples from 1979 Labrador samples were of Y-O-Y cod (Fig. 20). In analyses of 1980 Labrador material, deGraaf et al. (1981) found that the otoliths from small gadid fishes (*Gadus* spp. and *Boreogadus saida*) could not be safely separated. Although it appeared that age 0+ otoliths used in this study were from Arctic cod, it seems likely that some *Gadus* spp. otoliths were mistakenly included in our samples. For this reason, comparisons involving material from 1979 Labrador samples should be viewed with discretion. Otoliths of 1+ and older fish were clearly from *B. saida*.

AGE-FREQUENCY DISTRIBUTIONS OF ARCTIC COD OTOLITHS IN SEABIRD SAMPLES

Otoliths of Arctic cod have been found in most of the seabird species collected in the eastern Canadian Arctic (Bradstreet 1976, 1977, 1979, 1980, 1982; Bradstreet and Cross 1982). For the purposes of this report, we compare age-frequency distributions of otoliths from two species: northern fulmar and thick-billed murre. The fulmar is a near-surface feeder while murres catch their prey by pursuit-diving. Analyses of the contents of seabird stomachs employed somewhat different techniques than did the analyses of mammal stomachs described above. No subsampling of otoliths in seabird stomachs was undertaken. Also, unlike the case with marine mammal samples, many of the otoliths present in fulmar and especially murre stomachs were broken; thus, ages could not be determined. These otolith parts are not considered herein. Most broken otoliths were relatively large, but we have assumed that, within species, the tendency to find broken otoliths is similar from sample to sample. Among-species comparisons involving otoliths from seabird samples must be viewed with discretion given the numbers of broken and unusable otoliths present in the samples.

There was no significant difference due to year (1976 vs 1978) in the age-frequency distributions of Arctic cod otoliths in stomachs of northern fulmars collected on the open sea in Lancaster Sound and northwest Baffin Bay (Fig. 22; $P>0.1$) but this was probably due to small sample sizes. There were, however, significant differences in several comparisons involving otoliths from thick-billed murres (Fig. 23). The age-frequency distribution at the Barrow Strait ice edge in 1976 was quite different from that at the Pond Inlet ice edge in either 1978 ($P<0.01$) or 1979 ($P<0.01$); ages at Pond Inlet in 1978 and 1979 were similar ($P>0.1$). Age distributions also differed among years for collections made later in the summer when murres were taken on the open sea in Lancaster Sound and northwest Baffin Bay. Age distributions in 1976 and 1979 were similar ($P>0.1$), but significantly different in each of 1976 and 1979 than in 1978 ($P<0.01$). Cod taken in 1978 tended to be younger than those taken in 1976 or 1979. These comparisons suggest that year was an important determinant of age distribution of cod otoliths in murre stomachs. In contrast, ages of cod taken by ringed seals did not differ significantly between years (e.g. Fig. 15).

AGE-FREQUENCY DISTRIBUTIONS OF ARCTIC COD OTOLITHS IN FISH COLLECTIONS FROM THE BEAUFORT AND CHUKCHI SEAS

Otoliths from whole Arctic cod collected in Simpson Lagoon, Beaufort Sea, and from near Point Lay, Chukchi Sea, were available for analysis (Fig. 24). In three comparisons testing for year effects, no significant differences in age-frequency distributions were found (all $P>0.1$). There was also no significant difference in the age distributions of whole cod from the Beaufort Sea versus the Chukchi Sea ($P>0.1$).

AGE-FREQUENCY DISTRIBUTIONS OF ARCTIC COD OTOLITHS IN DIFFERENT PREDATORS COLLECTED AT THE SAME PLACE AND TIME

In five cases, two or three different predators were taken at the same time and location (Fig. 25). Analyses of the otoliths found in different predators are analogous to traditional comparisons of fish samples collected by different gear types (e.g. fyke nets, gill nets, trawls). Since we assume that different predators utilize food resources in different ways, comparisons of age-frequency distributions might, for example, give information on age-class segregation of cod by depth. Marine mammals have different diving capabilities (see below), and the murres collected at the Pond Inlet ice edge were probably foraging at the ice undersurface (Bradstreet 1982). But in eight of nine comparisons possible, no significant differences in the age-frequency distributions of cod taken by different predators were found (all $P>0.05$). This held true even in comparisons involving otoliths from thick-billed murres, which, as indicated above, may have been biased towards younger (smaller) year classes. In one comparison (harp seals vs ringed seals taken at Pond Inlet during the open-water season of 1978), the difference in otolith age distributions was marginally significant ($P<0.02$). We conclude that cod are either not strongly depth-segregated by age, or that in the five cases shown in Fig. 25, predators were all feeding at the same depth. This latter explanation seems quite unlikely. The presence of bottom fish in narwhal stomachs suggests that narwhals were deep-diving to feed (Finley and Gibb 1982; see below). Murres collected at the same time and place (two cases in Fig. 25) were diving for short periods of time and were undoubtedly feeding at the ice undersurface or in the upper water column (Bradstreet 1982). Thus, the results suggest, but do not prove, lack of strong depth segregation by age.

In summary, we have presented many comparisons of the age-frequency distributions of Arctic cod otoliths found in predator samples or fish collections. Ringed seal samples provided a large number of otoliths from a large geographic area but, after controlling for possibly confounding effects, we found no significant differences attributable to amount of food in the stomach, age of seal, season, habitat, area, or year. When ringed seal samples were grouped, however, large-scale area differences were apparent in the age-frequency distributions.

Analyses of Arctic cod otoliths from other marine mammal, seabird and fish samples provided support for the premise that there were significant large-scale area differences in the age composition of cod populations. In addition, there was some indication from the analysis of murre samples that age-frequency distributions of cod otoliths varied from year to year.

Another main finding was that different predators collected at the same time and location were apparently feeding on the same population of cod as far as its age structure was concerned.

REGIONAL DIFFERENCES IN AGE-FREQUENCY DISTRIBUTIONS OF ARCTIC COD OTOLITHS

Based on the material analysed in the previous section, it seems justifiable to group Arctic cod otolith data from all predators together and then to look for regional and year effects in the age structure of cod populations.

The regions defined for the purposes of these comparisons (and many of those made throughout the rest of this report) were largely arbitrary. It was not difficult to justify keeping data from areas like the Chukchi, Beaufort and Labrador seas separate. However, in the Canadian high Arctic, where samples were collected from many areas, we defined regions based on the discreteness of the data base. Samples from the Grise Fiord and Clyde River areas were geographically distinct from nearby collections so they were considered as regions. Samples were collected from Barrow Strait, Lancaster Sound and northwest Baffin Bay during three years but it was sometimes difficult to assign specific collection localities to one of these three contiguous water bodies since their boundaries are imprecise. Therefore, all samples from these areas were grouped into one region called Baffin. There was good evidence that otoliths from different locations near Pond Inlet had different age structure characteristics. Otoliths from Kounuk (Eclipse Sound) and the village of Pond Inlet were combined and analyzed separately from otoliths collected near the ice edge across the mouth of the inlet. The two resulting regions were called 'Pond--village/Kounuk' and 'Pond--ice edge'. Data from white whales collected in Creswell Bay in 1975 were excluded from regional analyses since many otoliths were highly abraded. Overall, eight regional populations of Arctic cod were available for comparison.

We found significant differences due to year in two of the five regions for which adequate data were available (Fig. 26). In both the Baffin and Pond--ice edge regions, age 1+ otoliths were the modal class in 1978, whereas age 2+ otoliths were the modal class in 1979 (Kolmogorov-Smirnov $P<0.01$). There were no significant differences in the age structure of cod populations between these two regions in either 1978 or 1979 ($P>0.05$). Cod otoliths collected in the Baffin region in 1976 tended to be younger than in either 1978 or 1979 ($P<0.01$).

In the Pond--village/Kounuk, Grise and Beaufort regions, year-to-year differences in age-frequency distributions were not significant ($P>0.05$).

Data from all years were combined for inter-regional comparisons (Fig. 26). The clearest inter-regional differences involved Baffin and Labrador; age-frequency distributions were similar ($P>0.1$) in these two regions and significantly different in each from every other region ($P<0.01$). This was due to the preponderance of young fish in the Baffin and Labrador collections (see mean ages in Fig. 26). In three other regions (Grise, Clyde, Chukchi) with similar frequency distributions (all $P>0.05$), the mean age of cod was relatively old. In between these two extremes of mean otolith age were three regions (Pond--village/Kounuk; Pond--ice edge; Beaufort) with cod of intermediate age and similar frequency distributions. Age-frequency distributions of otoliths from regions in this last group were significantly different ($P<0.01$) from distributions in the other two groups in eight cases and similar ($P>0.02$) in seven cases.

The observed inter-regional differences could have been due to real geographic effects or partly or wholly due to the year effects described above (i.e. disproportional representation of otoliths collected in different years). Some differences may also have resulted from artifacts mentioned earlier (i.e. misidentification of age 0+ otoliths from Labrador, differential breakage of otoliths from bird samples). In order to further investigate inter-regional differences, we looked at otoliths of similar ages from each of the eight regions (Fig. 27, Table 21).

In four of eight regions it was possible to test for year effects on the size of otoliths of a given age (Table 22). We found significant differences ($P<0.01$) in 5 of 24 possible comparisons. These differences involved age 1+, 2+ and 4+ otoliths from Grise Fiord and Pond--ice edge.

Tests on age 0+, 3+ and 5+ otoliths from all regions indicated significant inter-regional differences for each age class (all ANOVA $P<0.01$). For age classes 1+, 2+ and 4+ we compared otolith lengths at age for those regions not demonstrating a year effect. Again we found significant inter-regional differences ($P<0.01$). Finally, comparisons of length at age between Grise and Pond--ice edge were similar for age classes 1+ and 2+ in 1978 ($P<0.01$) but not in 1979 ($P>0.05$). Thus, cod otoliths of a given age can differ in size with year and region.

Combined with the results from comparisons of age-frequency distributions, we conclude that year and region both have significant influence on the age composition and size of cod otoliths found in predator samples. In the next section of the report we investigate the growth rates of Arctic cod otoliths in different regions and years.

GROWTH OF ARCTIC COD

The study of growth in fish populations has traditionally employed one of two main methods: direct measurements of fish (fork) lengths-at-age, with the subsequent development of growth equations (e.g. Von Bertalanffy, Ford, etc.); or indirect estimates of length-at-age determined by back-calculation. Back-calculation involves determining the age of a fish through examination of appropriate structures, usually scales or otoliths, and measuring the lengths of such structures at various annular marks. The lengths-at-age of the scales or otoliths are then converted into estimates of fish length-at-age through an equation relating scale or otolith length to fish (fork) length. These estimates of fish length are then used in developing growth equations.

Whole fish are rarely present in predator samples. Thus the direct method of measuring fish growth outlined above is not possible. The indirect method of back-calculation would be useful, however, if there were a general relationship between otolith length and fish length.

In all examinations conducted to date, including those in the present study (raw data in Appendix 4), the relationship between otolith length and fish (fork) length in Arctic cod has been found to be linear with a positive intercept (Bain and Sekerak 1978; Lilly 1978; Frost and Lowry 1980, 1981; Table 23). The two variables have always been found to be significantly correlated (Table 23; all $P<0.01$).

Raw data were available for 11 of the 13 relationships listed in Table 23 (not for the studies of Frost and Lowry 1980, 1981, or Bain and Sekerak 1978); these data allowed us to test for homogeneity of slopes following Sokal and Rohlf (1969: 452). The 11 regressions shown in Fig. 28 did not come from populations with equal slopes ($F_{9,965} = 7.49$, $P<0.01$). Since the slope of the regression for the Tremblay Sound data was grossly different from other slopes (Table 23, Fig. 28), this case was removed from consideration; the remaining 10 cases still had unequal slopes ($F_{8,876} = 5.75$, $P<0.01$). The next-most disparate slope came from Labrador Sea data; when this case was also removed from consideration, slopes in the remaining nine cases were still significantly different ($F_{7,836} = 2.75$, $P<0.01$). We conclude that there are significant differences in the relationship between otolith length and fish (fork) length from area to area.

For three areas, data were available from more than one year (Simpson Lagoon, Cornwallis Island, Button Point; Table 23). In two of these areas (Simpson Lagoon, Cornwallis Island), yearly slopes were indistinguishable ($F_{2,392} = 4.597$, $P>0.05$ for Simpson Lagoon; $t = 0.72$, $df = 285$, $P>0.1$ for Cornwallis Island). At Button Point, slopes were significantly different in 1978 and 1979 ($t = 4.24$, $df = 85$, $P<0.01$). Thus, in at least some areas there are significant differences in the relationships between otolith length and fish (fork) length between years.

For specific situations where a reasonable range of fish lengths are present, there are close relationships between otolith length and fork length. However, the above analyses show that estimates of the fork lengths of Arctic cod may be erroneous if they are derived from otolith length-fork length relationships developed in other areas or times. Since it was not possible to collect whole Arctic cod from each area where predators were taken, standard approaches to back-calculation were inappropriate. Indeed, since most predator samples contain mostly or only otoliths, the point of estimating growth based on direct or indirect measurements of total fish lengths is moot. What is needed are techniques that permit statistically valid comparisons of growth in the otoliths themselves.

In this section of the report we present two such techniques. One is based on the traditional back-calculation method in that measurements of otolith lengths at annular marks are made. But these measured otolith lengths are not then converted to estimates of fish lengths; rather, the actual otolith measurements-at-age or the differences in otolith lengths between successive ages are used in statistical comparisons of growth. The second technique employs a traditional method (Ford equations and Walford plots) but is based on otolith lengths rather than fish lengths. We demonstrate that there are no significant differences between growth coefficients determined from otoliths directly and those determined from measured fish (fork) lengths.

MEASUREMENTS OF OTOLITH LENGTHS AT PREVIOUS ANNULAR MARKS

Measurements of lengths at annular marks were performed on selected otoliths from seven regions (Baffin Bay, Grise Fiord, Pond [village/Kounuk/ice-edge samples combined], Clyde River, Labrador, Beaufort Sea and Chukchi Sea). Otoliths were chosen for analysis based on their readability and abrasion codes and no attention was paid to the source of the material. Thus, otoliths from various predators or whole fish could be used in this analysis. We attempted to select 20 otoliths of each age class of cod (0+ to 5+) from each region in each year. At times smaller sample sizes were considered in order to provide broad geographic coverage and at times larger sample sizes were used because large numbers of measurements of otoliths in a particular age class, region and year were already available from methodological tests. Numbers of otoliths used in the comparisons made in this section are given in Table 24.

In order to understand the approach used in the analysis of these measurement data it is perhaps best to consider a simple example. In 1978, Arctic cod otoliths from fish aged 5+ years old were available from Pond and Grise (Table 24); these otoliths represented fish that hatched in 1973. But otoliths from fish that hatched in 1973 were also sampled in 1977. These otoliths, which were collected in the Beaufort and Baffin regions, were from fish aged 4+ years old. The lengths of otoliths representing all fish hatched in 1973 could be measured at four annular marks, called rings (R_1 to R_4). These were the ring-to-ring measurements described in the methodological section. The differences between pairs of ring measurements could also be calculated; these differences (e.g. R_4-R_3) were called growth increments. The difference between the first annular ring and the otolith's length at age 0+ was assumed to equal the distance between the first annular ring and the centrum. Comparisons of otolith growth between regions were based on all of these measurements and calculated differences.

Statistical comparisons of ring measurements and growth increments used non-parametric methods: Mann-Whitney and Kruskal-Wallis tests. When Kruskal-Wallis tests were significant, Dunn's multiple comparisons were used to indicate significant pairwise differences. Probability values <0.01 were considered significant.

1973 cohort

Otoliths from Arctic cod that hatched in 1973 were collected in two regions in 1977 and in two additional regions in 1978.

Otolith lengths at the first annular ring were similar in all four regions (Table 25) but there were significant differences in growth between the first and second years (1974-75). Dunn's comparisons showed that otolith growth at Grise (mean increment 2.7 mm) was significantly greater than at Pond (1.8 mm). By age 3+ there were no significant differences in otolith lengths among the four regions; apparently growth at Pond occurred quickly enough to compensate for the lag in growth that had occurred between age 1+ and age 2+ in this region versus Grise.

1974 cohort

Otoliths from Arctic cod that hatched in 1974 were collected in two regions in 1977, in four regions in 1978 and in two regions in 1979.

Significant inter-regional differences were found in all ring measurements and in three of four comparisons of annual growth increments (Table 26). At age 1, measurements were significantly greater in the Beaufort region than elsewhere. In the next two successive annual growth increments, there were significant inter-regional differences, growth at Pond was significantly less than at Grise, and resulting ring measurements continued to demonstrate significant inter-regional variability. Beaufort otoliths remained the largest and Pond otoliths remained the smallest during these two years. There were no significant inter-regional differences in otolith growth from the third to fourth rings, but the previously significant differences in length-at-age were apparently maintained in measurements of the fourth growth ring. Beaufort otoliths were consistently largest-at-age in this cohort; Grise otoliths began as the smallest and ended as equal to the largest; and Pond otoliths, ranking second-largest at the first growth ring were comparatively the smallest at the fourth growth ring.

1975 cohort

Otoliths from Arctic cod that hatched in 1975 were collected in two regions in 1977, four regions in 1978 and three regions in 1979.

There were significant inter-regional differences in two of three ring measurements and in all three annual growth increments (Table 27). At age 1, measurements were significantly larger in the Beaufort region than elsewhere. There were again significant inter-regional differences in the second growth increment, but otoliths from the Beaufort region had the least growth. This resulted in otoliths of similar size in all five regions at the end of the second year of growth. During the third year, growth increments again showed significant inter-regional variability with growth in the Baffin region being least and that at Grise being greatest. Otolith lengths at the third annular ring were also significantly different on a regional basis, with those at Pond being smallest and those in the Beaufort being largest.

1976 cohort

Otoliths from Arctic cod that hatched in 1976 were collected in four regions in 1978 and four regions in 1979.

All inter-regional comparisons were significant (Table 28). Otoliths grew significantly larger during the first year in the Beaufort region than elsewhere. During the second year, growth increments were similar at Pond and in the Beaufort, but significantly less in each of these two regions than elsewhere. At the end of the second year of growth, Pond and Beaufort otoliths were similar in size but they were significantly smaller in these two regions than elsewhere.

1977 cohort

Otoliths from Arctic cod that hatched in 1977 were collected in three regions in 1978 and four regions in 1979.

There were significant inter-regional differences in the first growth increment (Table 29). Measurements from the Pond, Grise and Baffin regions were similar and significantly less than those from the Labrador or Beaufort regions.

1978 cohort

Otoliths from Arctic cod that hatched in 1978 were collected in two regions in 1978 and in three regions in 1979.

There was no difference in the total lengths of age 0+ otoliths collected in the Pond or Baffin regions (Table 30). In age 1+ otoliths collected in 1979 we found significant inter-regional differences in the first growth increment. Otoliths in the Pond and Grise regions were of similar size and significantly smaller than those in the Labrador region. During the time between the deposition of the first annular ring and the collection of the otoliths, growth of otoliths from Pond (mean increment 1.1 mm) and Grise (1.2 mm) was much greater than in those from Labrador (0.3 mm).

1979 cohort

Otoliths from Arctic cod that hatched in 1979 were collected in two regions in the same year (Table 31). Total lengths of age 0+ otoliths collected in the Pond Inlet region were significantly less than those collected in Labrador.

Temporal and regional differences in otolith growth

The above accounts of differences in otolith growth between and among regions for Arctic cod that hatched in various years demonstrate several patterns. Synthesizing that information is a difficult task, given the number of regions and cohorts of cod and the differing amounts of data available for (and hence the reliability of) the comparisons. In this section we look for temporal and regional differences in otolith growth, restricting the analyses to annual growth increments of the younger age classes of cod (up to age 3+), for which most data are available.

We considered only those regions and hatching years for which data were available for ages up to 3 (Table 32; i.e. data from Clyde were not considered). This restriction permitted blocked analyses of variance (Friedman tests) of growth increments, with region and year-of-hatching as the two factors. After blocking by region, we found no significant year effects in comparisons of annual growth increments (Friedman $P>0.1$ in three comparisons). After blocking by year, there was a marginally significant region effect (Friedman $S' = 8.13$, d.f. = 3, $P<0.05$). Rank sums indicated that growth rates decreased from Grise (34) and Beaufort (33), through Pond (23) and Baffin (20). Thus, there was no clear pattern in growth rates across the North American Arctic.

DEVELOPMENT OF GROWTH COEFFICIENTS FOR ARCTIC COD: A COMPARISON OF METHODS BASED ON OTOLITH AND FORK LENGTH MEASUREMENTS

As stated above, most of the Arctic cod material that can be obtained from predator samples (stomachs, feces) consists of otoliths. Estimates of coefficients of fish growth can be developed from such otolith material using standard fisheries techniques (e.g. Ford growth coefficients, Walford plots) but it is important to demonstrate that the otolith-derived growth rates are similar to the more conventionally-derived rates developed from measurements of fish (fork) lengths.

During this study, four collections of whole Arctic cod from widely disparate North American localities were used to test the hypothesis that growth coefficients determined from otoliths do not differ from those determined from fork lengths. In these collections, fork lengths of the fresh fish were measured, and otoliths were removed from the fish and also measured. Fish ages were determined independently by two observers through otolith readings. Mean lengths-at-age were then calculated from both the otolith and fork length measurements. Walford equations, which compare the length of a fish (or otolith) at age X+1 with its length at age X for successive pairs of ages, were developed and the slopes of these equations (equivalent to Ford's growth coefficients) were compared statistically (Table 33). We found no significant differences in growth coefficients determined from otolith or fork length measurements. Figure 29 shows the overall similarity of slopes derived by these two methods. We conclude that growth coefficients derived from otoliths do not differ significantly from those derived from fork lengths.

Growth coefficients determined from otolith lengths

Mean lengths of otoliths, 1+ to 7+ years old, were calculated for various regions (Table 34). Walford equations were then calculated for those regions with more than 250 otoliths. Age classes for which fewer than 10 otoliths were available were not included in the calculations. In plots from several regions with adequate data it was clear that, at young ages, slopes (equivalent to Ford's growth coefficients) were greater than at older ages (Fig. 30). Generally, slopes increased until about age 3+ and decreased thereafter. Growth coefficients were recalculated for these two 'stanzas' of growth (Table 35 and Fig. 30).

Ford's growth coefficients (the slopes of the Walford equations) were tested for homogeneity with an analysis of covariance (Sokal and Rohlf 1969: 452). We found no significant heterogeneity within any of the three groups of coefficients tested (Table 35). This was surprising, given the large range of values present within each of the three groups. Lack of significance likely occurred because of the small sample sizes used in developing the Walford equations and subsequent statistical comparisons; each pair of adjacent ages contributes only one unit to the sample size in such analyses.

Generally, all fish 'exhibit an initial period of increasingly rapid absolute increase in length, followed by a decrease' (Ricker 1975:205). The intersection of the Walford lines replotted through the upper and lower series of points indicates the age at which Arctic cod enter the second, slower growth stanza. Figure 30 shows that in all regions except the Beaufort, Arctic cod entered this second phase of growth at or after age 2+; in the Beaufort region the intersection of the replotted Walford lines suggests that fish entered the second stanza of growth between the first and second years. Growth coefficients for the second stanza of growth in the Beaufort region were then recalculated, incorporating data from age 2+ fish.

Mean coefficients of growth for the two stanzas were found to be significantly different (mean for rapid stanza 1.64, mean for slower stanza [using recalculated Beaufort value] 0.70; Mann-Whitney P = 0.004).

Growth coefficients determined from fish lengths

Measured fish (fork) lengths of Arctic cod were available from seven areas (Table 36). Ford's growth coefficients calculated from these data were tested for homogeneity. No significant difference was found in an analysis of covariance ($F_{6,11}$ = 1.00, P>0.05) and we conclude that growth rates determined from measured fish lengths did not differ significantly among the seven areas.

Growth coefficients determined from otolith lengths (mean value of 0.906, Table 35) and fish lengths (0.808, Table 36) were not significantly different (Mann-Whitney U = 25, P>0.1).

DISCUSSION

Walford equations use the ratio of mean otolith lengths (or fork lengths) at each pair of successive ages as a single datum, even though the number of otolith (or fish) measurements contributing to this single value may be very large (in the thousands in some cases). Since Arctic cod are short-lived fish (i.e. since the number of ages, and therefore the sample sizes, will always be small), Ford's growth coefficients may be inappropriate for comparing growth of Arctic cod among various regions.

Although we were unable to demonstrate inter-regional differences in growth using Ford's coefficients, we did demonstrate significant differences in the lengths at age and growth increments of cod otoliths among regions. Most such inter-regional differences were shown using small subsamples of the otoliths available, otoliths that had been chosen for good readability and little or no abrasion.

We have also demonstrated significant inter-regional differences in total otolith lengths-at-age (Table 22), and in a few cases, significant year effects in lengths-at-age. In these cases, large numbers of otolith lengths were compared. For example, we collected many otoliths of one- and two-year-old fish at Grise Fiord in 1978 and 1979. The total lengths of these otoliths were significantly different between years (Table 22). When small subsamples of the otoliths from age 1+ fish were looked at more closely, significant differences were found not only in the total lengths, but also in the first growth increment (Table 37). That is, growth in one-year-old fish differed significantly between the 1977 and 1978 hatching years. When subsamples of age 2+ otoliths were examined in detail, the first growth increment and otolith length at R_1 were similar; growth in one-year-old fish did not differ between the 1976 and 1977 hatching years. But there were significant differences in the second growth increment, again demonstrating significant differences in otolith growth between 1977 and 1978. In each of these two cases the same trend was demonstrated; otolith growth was less in 1978 than in 1977. There can be significant differences in the growth of cod otoliths from year-to-year within the same region. These year effects can affect more than a single year class of cod simultaneously.

In summary, we have found significant inter-regional and inter-year variation in the growth of Arctic cod. Differences in fish growth were demonstrated using measurements of otoliths, on the assumption that otolith length and fish length are closely related. We demonstrated that this was so. Comparisons of total otolith lengths-at-age provide strong evidence of inter-regional differences in growth and some evidence of inter-year differences in growth within regions. Measurements of annular growth increments in otoliths permit detailed statistical comparisons of regional differences in growth and of temporal differences in growth within a region. Traditional methods of determining growth in fish (Ford's coefficients) are unlikely to show regional differences in the growth rates of short-lived fish such as Arctic cod, even if such differences are large. We conclude that otoliths collected from predator samples provide a good mechanism for monitoring regional and temporal variation in the growth of Arctic cod.

MORTALITY RATES OF ARCTIC COD

Fisheries biologists have traditionally used 'catch curves', which are plots of the numbers of fish ($\log_{10}$) in different age- or length-classes, to investigate aspects of the mortality of fish populations (Ricker 1975).

The fish used in these analyses have almost always been taken from fish populations harvested by man; indeed, estimates of mortality in unexploited populations are rarely available. In this study, we have used the Arctic cod otoliths in predator stomachs and feces to investigate cod mortality. The various predators were, in effect, different types of sampling gear. Since no significant harvesting of Arctic cod occurs by man in the area where the predators were collected (eastern Canadian Arctic), catch curves compiled from our data can be used to investigate the total natural mortality of Arctic cod. Data from all marine mammal and seabird samples were used in these analyses.

Catch curves consist of three parts, an ascending left limb, a domed top and a descending right limb. The ascending limb indicates that non-random sampling of the population is occurring: fish of younger age classes are taken less frequently in relation to their assumed abundance than are older fish. The dome of the curve represents ages at which fish have been fully recruited into the catchable population (i.e. fish of all ages beyond this point are equally vulnerable to predation). The right limb of the catch curve, specifically its slope and curvature, gives information about the rate and nature of fish mortality. It should also be noted that there is a possibility that some of the apparent scarcity of younger age classes is real and not a sampling artifact. Johnson (1976, 1983b) demonstrated that the length distributions and sometimes the age distributions of numerous populations of Arctic char (Salvelinus alpinus) and to a lesser degree lake trout (Salvelinus namaycush) and lake whitefish (Coregonus clupeaformis) are naturally bimodal. There is thus a natural scarcity of fish of intermediate size or age.

For a given predator species, full recruitment of Arctic cod into the catchable population occurs at different ages in different years (Fig. 31). These moderate fluctuations in catchability-at-age are neither unusual nor significant in the subsequent development of estimates of mortality rates. Generally, data from several years are combined in calculating mortality rates (Ricker 1975); such an approach has been followed herein. Catch curves based on data from predators collected in different areas also varied in terms of the age at which Arctic cod were fully recruited into the catchable population (Fig. 32); data from these areas were kept separate. We have shown, previously, some significant differences in the age class structure of cod on a regional basis and varying mortality rates may be important components of the observed differences.

Mortality rates were calculated following Baranov (Ricker 1975: 33) using the modal age in the catch as the age of recruitment (i.e. the age at which catchability became uniform). Since Arctic cod are relatively small (well within the maximum size limits of foods eaten by the mammal predators and near the maximum size limits of foods eaten by fulmars and murres), we assumed that the predators were not selecting any particular size/age class of cod beyond the recruitment size/age. Data from each predator species and area were assumed to be independent; resulting mortality values were therefore also assumed to be independent estimates of true mortality.

There appeared to be no regional variation in mortality rates of Arctic cod (Tables 38 and 39) at least among the four regions that could be compared statistically. Mortality rates increased with age (Table 38); they were similar for age classes 1+ to 3+ and increased gradually thereafter. These results are reflected in the shapes of the catch curves; most are convex in shape from the age of modal catch to age 6+ (Fig. 32 and 33). Mortality rates that increase with age are typical of unfished fish populations (Ricker 1975).

Although we found no significant differences in mortality rates among the four regions for which minimally-adequate data were available, it is possible that such differences do exist. Mortality rates at the Pond Inlet ice edge were consistently higher than elsewhere. We also found that recruitment of Arctic cod into the catchable population varied from year to year. If temporal trends in recruitment over broad geographic areas exist, then calculation of mortality rates on an annual or biannual basis would allow such changes to be monitored. Significant changes in the mortality rates of Arctic cod over time or from area to area could have serious effects on the distributions and long-term population dynamics of dependent predators. Clearly, data sets which are more comprehensive in temporal and geographic extent are required to address these topics. However, this study has shown that otoliths collected from predator samples provide a means of estimating total mortality in Arctic cod populations.

MARINE MAMMAL PREDATION ON ARCTIC COD IN THE EASTERN CANADIAN ARCTIC

Recent studies have demonstrated conclusively that Arctic cod is very important in the diets of many northern marine birds and mammals. Arctic cod are short-lived, rapid-growing, early-maturing fish (Craig et al. 1982). Theory suggests that such r-selected species are less severely limited than are K-selected species (long-lived, slow-growing, late-maturing) by density dependent factors, such as resources or predators. As Craig et al. (1982) note, 'If a regulatory effect does exist, it is probably exerted on the predators because population sizes of an r-selected species may be erratic, given the presumed controlling influence of variable, unpredictable, or catastrophic mortality factors'. In this section of the report we investigate certain aspects of predation on Arctic cod by marine mammals in the eastern Canadian Arctic. We synthesize the available information on the role of Arctic cod in the feeding behaviour and distribution of selected marine mammal predators, we use measurements of otolith size and age to analyze the population structure of Arctic cod sampled by the predators, and we evaluate the predator as a sampling device, incorporating knowledge of Inuit hunting patterns and the distribution and habits of their marine mammal prey.

SEASONAL PATTERNS OF INUIT HUNTING

To begin to interpret something of the distribution and natural history of the Arctic cod, it is necessary to understand where and under what special circumstances the predators were taken. This largely depends on ice conditions, which regulate the mobility of the local people. Thus in this report, the seasonal designation is adapted to local conditions (e.g. summer is synonymous with the open-water season when it is possible to travel by boat) and partly arbitrary (e.g. early winter vs late winter). The seasonal designations are broadly similar throughout the eastern Arctic; they depend on the time of ice formation and break up and the proximity of hunting communities to ice edges. Ice-edge hunting is a specialized type of hunting for many of the indigenous people inhabiting the shores of Baffin Bay (M'Clintock 1859; Wenzel 1981; Finley and Miller 1982). Figures 34 and 35 illustrate the patterns of kills of ringed seals taken during the year at Pond Inlet and Grise Fiord.

Open-water

The open-water season begins as soon as the pack ice disperses sufficiently to allow hunters to travel by canoe. In the eastern Canadian Arctic this usually occurs by early August, although unrestricted travel may not be possible until late August. The open-water season usually lasts until early October when new ice begins to form. Most of the hunting during this period is conducted from outboard-powered boats or canoes in sheltered waters, i.e. fiords, coastal areas and ice fields. Occasionally marine mammals are shot from strategic shore-based positions.

Most of the migratory species as well as ringed seals are taken during the brief open-water season. Hunting is conducted on an opportunistic basis, although the techniques are specially adapted to the circumstance and behaviour of the species being hunted. Ringed seals, particularly the immature animals, are quite inquisitive. They can usually be approached and shot from slow-moving boats; often the seals are induced to approach stationary boats or ice pans by hunters making scratching sounds. After mid-August ringed seals become more buoyant with acquired blubber reserves and usually float when shot. However, bearded seals sink when killed so the hunters must attach a float (by harpooning) before killing the seal. Harp seals are wary of boats and must be actively pursued by the hunters; the most successful hunting is conducted under calm conditions when hunters can keep track of the movements of seals until they can be approached quite closely. Harp seals usually sink quickly after being killed and must be harpooned immediately to prevent loss. During the open-water season at Pond Inlet, the majority of the seals are taken within fiords or fiord complexes (e.g. Pond Inlet-Eclipse Sound). Typically the fiords are steep-sided and deep (generally 100-500 m). The more offshore distribution of ringed seal kills at Grise Fiord than at Pond Inlet is due to the persistence of ice fields in Jones Sound; the ice provides shelter to the hunters (Fig. 34 and 35). Since harp and bearded seals are usually taken incidentally during ringed seal hunts, patterns of kills are assumed to be similar to those mapped for ringed seals in Fig. 34 and 35.

Narwhals and white whales are usually driven into shallow coastal areas before they are harpooned and shot (see descriptions by Finley et al. 1981; Finley and Miller 1982; Finley et al. 1982).

Early winter

During freeze up, ringed seals are actively hunted at their breathing holes in areas of thin ice that are easily accessible from the villages or hunting camps. As the ice becomes thicker and the seal holes become more difficult to find, the hunting switches to ice cracks and the hunters range farther from the settlements. This period of hunting usually tapers off by late November due to darkness.

Late winter

As light returns, hunting for ringed seals resumes, particularly during February and March. At Grise Fiord most hunting continues to be conducted along recurrent ice cracks near the settlement. However, at Pond Inlet hunting shifts to the ice-edge zone bordering Baffin Bay. Ice-edge hunting is much more productive than ice-crack hunting and thus many more seals are taken during this period at Pond Inlet than at Grise Fiord; the latter is not located near the winter ice edge. A large proportion of the ringed seals taken in ice cracks and at ice edges tend to be immature animals, apparently excluded from fast-ice breeding habitat. Because of the formative processes behind recurrent ice cracks and ice edges, seals taken in these features tend to be found over deep waters; e.g. depths along the Pond Inlet ice edge generally range between 200 and 600 m.

Although April and May are included within the 'late winter' season, ice crack and ice-edge hunting tend to decrease and more effort is shifted toward hunting of neonatal seals in their birth lairs. Thus we have few stomach samples for these months.

Haul out

Spring begins when the snow lairs of the seals start to collapse and the seals begin to haul out on the ice for extended periods to encourage moult. Haul-out occurs from early June to mid July. Although some basking adult seals are shot in the spring, their skins are poor and their meat is not deemed highly palatable compared to the young-of-the-year, which are strongly preferred at this time of year. The few adult and immature seals that are taken seldom have much in their stomachs; thus we have few otolith samples from seals during the haul out period. Some of the seals taken during haul out at Pond Inlet were taken at or near the ice edge (Fig. 34). These seals were taken incidentally to the spring narwhal hunt, a traditional occupation among the hunters from northern Baffin Island (Finley and Miller 1982). Narwhals taken along the Pond Inlet ice edge in the springs of 1978 and 1979 provided the basis for a study of their food habits (Finley and Gibb 1982).

PREDATOR DISTRIBUTION AND FEEDING BEHAVIOUR

All five marine mammal species examined in this study inhabit the Arctic archipelago during the summer season. The ringed seal, which can maintain breathing holes in solid ice, is the only one of these predators that can overwinter in much of this area (Degerbøl and Freuchen 1935; Vibe 1950; McLaren 1958; Mansfield 1967; Smith 1973). The bearded seal, having a limited capability to maintain breathing holes in solid ice, is largely restricted during the winter to areas of moving pack ice where openings are continually formed, or to areas with recurring ice cracks (Burns et al. 1981). Although movements by both these species are largely local in response to seasonal ice conditions, both ringed seals and bearded seals are known to travel long distances annually in certain parts of their range (Burns 1967; Burns and Frost 1979; Burns and Harbo 1972; Benjaminsen 1973; Smith 1976; Smith and Stirling 1978; Stirling et al. 1977). Harp seals, narwhals and white whales must undertake long migrations from their wintering grounds farther south to inhabit the archipelago during the open-water season (for review see Davis et al. 1980).

All five species are euryphagous, piscivorous predators that are known to feed heavily on Arctic cod when they are available (for review see Davis et al. 1980). Where such dietary overlap occurs, differing feeding strategies may be expected. To begin to interpret something of the biology of the Arctic cod, it is necessary here to review briefly what is known about the diet and feeding habits of the individual predators.

Ringed seal

Ringed seals are relatively solitary animals, although during the open-water season they sometimes form loose groups. During much of the year, they maintain territories delineated by breathing holes in suitable areas of fast ice. They also occur on drifting pack ice offshore, moving into coastal areas during the brief open-water season. Thus densities in certain nearshore areas can be quite high during the open-water season (Finley et al. 1983a).

Ringed seals are opportunistic feeders, taking the most available organisms from small crustaceans (mysids and amphipods) to larger fishes, depending on the area and season (Table 40). They forage within the water column and may feed close to (but seldom actually on) the bottom. In offshore areas, the pelagic amphipod Parathemisto libellula forms an important component of the diet. In nearshore areas the diet consists primarily of mysids, amphipods and fish (especially Arctic cod), depending on the area and season (Table 40). Several of the references cited in Table 40 lack details on sampling techniques so it is difficult to establish patterns of feeding associated with depth or location. In addition, discrepancies occur in the use of terms pertaining to specific areas of habitat. For example, Vibe (1950) stated that Arctic cod were the principal food of ringed seals in offshore areas, just the opposite to McLaren's (1958) findings in waters off Baffin Island. However, as noted by McLaren, Vibe's inshore/offshore designation appears to be more arbitrary than real. Despite these problems, it is evident that ringed seals in the northern seas of the USSR, Alaska, Canada and Greenland feed heavily on Arctic cod for much of the year. In deeper offshore waters, pelagic amphipods, particularly Parathemisto libellula, form a major part of the diet. In more southerly latitudes (e.g. Hudson Strait, Ungava Bay, Sea of Okhotsk) amphipods, mysids and euphausiids are more important in the diet (Dunbar 1941; McLaren 1958; Fedoseev 1965).

Although ringed seals are capable of feeding at two levels of the food chain, it is assumed that they will feed preferentially on the largest and most abundant prey (i.e. fish) for greatest energy returns. Thus if Arctic cod occur within the diving range of ringed seal, they will probably be represented in the diet. It is not certain how deep ringed seals are capable of diving or how deep they regularly forage. The closely related harbour seal (Phoca vitulina) may feed to depths of 100 m (Harrison and Kooyman 1968). We assume a similar vertical foraging range for the ringed seal. The scarcity of Arctic cod in the diets of ringed seals in more southerly areas (e.g. Dunbar 1941; McLaren 1958; deGraaf et al. 1981) suggests that the cod are nearly absent in coastal areas within the seal's diving range; however bottom trawls in adjacent offshore areas have shown that Arctic cod are quite abundant in deep (125-650 m) cold (<1°C) waters (MacLaren Marex Inc. 1978; Lear 1979a). Also Jensen (1948) noted that, although Arctic cod were thought to be absent in the more southerly fiords of Greenland, they in fact occurred (as a by-catch of the shrimp industry) in considerable numbers at depths between 240 and 360 m. Thus in some areas Arctic cod occur at depths beyond the normal feeding range of ringed seal.

Ringed seals have a seasonal cycle in feeding intensity (McLaren 1958; Lowry et al. 1980a; Bradstreet and Finley 1983). In general, during the breeding through moulting period (April-July) they feed relatively little and their blubber reserves decline. Following moult the seals feed intensively and acquire blubber reserves quickly; by mid September they are near peak condition. Feeding activity remains high throughout the winter.

Bearded seal

Bearded seals are solitary animals. They are most abundant in areas where they can reach the sea bottom to feed (generally <200 m) and where they have access to ice pans upon which to haul out (Burns and Frost 1979). The bearded seal has only a limited capability of maintaining breathing holes in solid ice and is therefore excluded from much of the Arctic where solid ice cover persists for most of the year (Burns et al. 1981). In winter they have been observed on drifting pack ice over the deep waters of Baffin Bay (Finley and Renaud 1980). During the summer they are found widely distributed in low densities throughout much of the archipelago.

The bearded seal is primarily a benthic feeder; however it is also an opportunist, taking whatever is available (Chapskii 1938; Kosygin 1971; Lowry et al. 1980b; Finley and Evans 1983). Although benthic fishes, such as sculpins (Cottidae), constitute much of the diet in the eastern Canadian Arctic, bearded seals will also feed heavily and sometimes exclusively on Arctic cod (Finley and Evans 1983). Presumably the cod are taken near or on the bottom, but this may not always be so, particularly where cod are abundant. Vibe (1950) stated that Arctic cod were of major importance in the diet of bearded seals in areas of northwest Greenland where they could not reach the bottom.

Bearded seals feed heavily during the summer in the eastern Canadian Arctic. The summer diet of individuals, which were collected (1978-80) largely within fiords close to three communities in this area (Grise Fiord, Pond Inlet, Clyde River) consisted predominantly of fishes and to a far lesser extent benthic invertebrates (Finley and Evans 1983). Local differences in the relative importance of various food items were evident. Burns and Frost (1979) believed that geographical variation in the diet of bearded seals in the Bering and Chukchi Seas was a reflection of local faunal differences. In the eastern Canadian Arctic, Arctic cod comprised a higher proportion of the fish in the stomachs of the seals taken at Grise Fiord (50%) than at Pond Inlet (16%) or at Clyde River (16%) (Finley and Evans 1983). Assuming that the proportional representation of Arctic cod in a bearded seal's stomach is roughly similar to the local availability of the prey, this suggests that Arctic cod are sometimes more abundant in the Grise Fiord area, compared to the Pond Inlet and Clyde River areas, during the open-water season.

Harp seal

Harp seals undertake long migrations into the high Arctic specifically to feed during summer. They put on large blubber reserves between the time they arrive in late June and when they depart in late September. Arctic cod are the focus of this feeding in the eastern and central Arctic, and the movement and local abundance of harp seals appears to be related to the abundance of Arctic cod (Finley and Gibb in press). The coincidence of the distributions of harp seals and Arctic cod, and the frequent association of harp seals with narwhals and white whales in feeding aggregations during late summer, provides a reasonable indication of areas with important concentrations of Arctic cod.

In some areas the appearance of harp seals is irregular from year to year, apparently depending on the availability of Arctic cod. For example, in 1978 harp seals were present in significant numbers in Eclipse Sound but in 1979 they were nearly absent in the same area (Finley and Gibb, in press). Supporting evidence from the diets of other predators (narwhals, ringed seals) indicated that Arctic cod may have declined in abundance in the same area between 1978 and 1979 (Finley and Gibb 1982, Bradstreet and Finley 1983). Harp seals were present in substantial numbers in Creswell Bay in late August 1976 (Finley and Gibb, in press), coincident with a large inshore movement of Arctic cod, but harp seals were absent in the summer of 1977 when cod were notably less abundant (Finley, unpublished data).

In other areas of the high Arctic, harp seals occur predictably in large numbers each year. The fiords along the south coast of Ellesmere Island appear to be particularly favoured and the residents of Grise Fiord regularly take, by far, the largest number of harp seals of any high Arctic settlement (Finley and Miller 1980). The stomachs of harp seals taken near Grise Fiord usually contain large numbers of Arctic cod. Another important area for harp seals (and thus Arctic cod) appears to be in the fiords along the south coast of Devon Island; particularly large feeding aggregations have been seen in the vicinity of Bethune Inlet in September (Table 41). Admiralty Inlet and Navy Board Inlet also appear to be favoured feeding areas of the harp seal, often in association with narwhals. By contrast, harp seals are rarely seen during summer along the east coast of Baffin Island between Lancaster Sound and Cumberland Sound. Harp seals are abundant off southeastern Baffin Island in Cumberland Sound and Frobisher Bay but it appears that their diet in these areas consists mostly of the amphipod Parathemisto libellula, euphausiids and mysids (Sergeant 1973). Along the Labrador coast, euphausiids constitute the bulk of harp seal's diet during their northward migration (Foy et al. 1981).

Harp seals are highly gregarious and are usually seen travelling rapidly, often porpoising, in tight groups of about 10-80 individuals. This organization and high mobility may reflect a strategy for locating fish. Relatively large schools of fish would be necessary to sustain a group of harp seals, since several hundred may occur in an area where they are feeding. Harp seals have been observed feeding in a synchronized manner, herding large schools of Arctic cod (Finley and Gibb, in press).

A decline in the weight of stomach contents of harp seals taken between late August and late September may indicate a dispersal of Arctic cod from nearshore areas of the high Arctic during this period (Finley and Gibb, in press). Evidence of this dispersal or decline in abundance has been observed in net catches of Arctic cod in late September in Barrow Strait (Bain and Sekerak 1978; Sekerak 1982a) and in the Beaufort Sea (Craig et al. 1982). By late September most harp seals have left the high Arctic. It should be noted that, although Arctic cod may decline in the harp seal diet at about the time that harp seals abandon an area, Arctic cod do not appear to decline in the diet of ringed seals in the same area at that time (Bradstreet and Finley 1983). This difference may be a reflection of the harp seal's need to feed on denser schools of prey than the ringed seal, which is primarily a solitary feeder.

Narwhal

During June narwhals appear along coastal ice edges in northwest Baffin Bay. Their movements are generally parallel to the ice edge but often interrupted by circling movements and dives. Feeding by narwhals along ice edges does not appear to be especially intensive; during the long periods that we have observed narwhals here we have seen only four instances of obvious feeding aggregations, usually in conjunction with white whales and harp seals (Table 41). In the two cases where it could be ascertained, by examining stomach contents of narwhals or by close observations, Arctic cod were the object of their feeding.

Arctic cod form a major part of the diet of narwhals at ice edges during spring. Apparently narwhals take the cod from the water column beneath the ice edge since their 'deep dives' are almost invariably directed beneath ice edges at a steep angle of descent. Water depth along ice edges where narwhals are taken is often over 500 m. The presence of bottom-dwelling fish, such as halibut, in these narwhal stomachs indicates that narwhals are able to forage to the bottom (Finley and Gibb 1982).

As soon as the solid ice begins to break up, narwhals undertake a major movement into their traditional summering areas, particularly the fiord complexes of northern Baffin Island. Although narwhals feed during this period, their onshore movement does not appear to be undertaken for the purpose of feeding. It appears to be more related to calving requirements. In fact, during most of August (the peak of calving) narwhals feed very little. Blubber measurements taken between June and September indicate that females decline in condition throughout the summer, while males maintain a constant blubber thickness (Finley and Gibb 1982).

During late August and September, with ice cover at its minimum extent, narwhals may be found throughout many of the channels of the eastern and central archipelago that are connected to Lancaster Sound, their primary access route. During this period narwhals appear to resume feeding and may be seen in feeding aggregations, often in association with other marine mammals (Table 41). These feeding aggregations are almost always observed in nearshore areas and appear to be related to an inshore movement of Arctic cod in late August and during September (see following section). Notable aggregations of narwhals during this period have been observed in the fiords along the south coast of Devon Island, Ellesmere Island (Grise Fiord), Creswell Bay, at the mouth of Navy Board Inlet (Wollaston Islands), and Pond Inlet.

White whale

White whales arrive in the high Arctic in late June/early July and move westward in Lancaster Sound to their summering areas in the central archipelago, particularly the coastal waters of Somerset Island. Like narwhals, white whales do not appear to migrate into the area to feed, but rather to calve and moult. During mid July to mid August they traditionally occupy certain estuaries where they moult and rear their calves. Their stomachs are usually empty at this time (Davis and Finley 1979); if otoliths are present, they are often very abraded (Appendix 3).

Little is known about the seasonal energy budget of white whales, but it appears that their blubber reserves are greatly depleted when they arrive in their summering areas. After mid August white whales disperse from the estuaries and begin to feed intensively. In early September, they begin their eastward migration through Lancaster Sound. It is during this time that large feeding aggregations have been observed in coastal areas, e.g. at Assistance Bay (Cornwallis Island), in various fiords along the south coast of Devon Island, and in Bethune Inlet along the southeast coast of Devon Island (Table 41, Fig. 36). Bethune Inlet is notable for its large aggregations of white whales, which appear regularly during the fall migrations (Koski and Davis 1979). White whales also occur regularly near Grise Fiord in autumn; these whales are often seen feeding in association with harp seals. In all cases where it could be determined, the white whales were feeding on Arctic cod. Some individual whales were glutted with cod; for example, an immature male taken at Resolute Bay contained 10 kg of Arctic cod (Finley, unpublished data). On at least three occasions, large numbers (Table 41) of Arctic cod have washed ashore in the aftermath of intensive feeding by white whales. Similarly, Ross (1835:110) stated of Arctic cod that 'their most destructive enemy is the delphinapterus beluga, or white whale; from its persecutions they have been known to leap on the ice by hundreds'. Klumov (1937) and Kleinenberg et al. (1964) have remarked on the close association of white whales with the abundance and movements of Arctic cod in the Soviet Arctic.

White whales are highly gregarious during their migrations and it is apparent that large numbers of cod would be required to sustain a herd of them. Thus the predictable occurrence of the large herds in certain coastal areas in late August and early September may be indicative of a major inshore movement of Arctic cod during this period.

Although the summer distribution of white whales appears to be more coastal than that of narwhals, recent studies have shown that white whales can easily dive to 400 m and are capable of reaching 650 m (Ridgway et al. 1984). Parts of the winter range of white whales occur over the deep waters of Hudson and Davis straits (Finley et al. 1982; McLaren and Davis 1982).

FEEDING AGGREGATIONS OF PREDATORS AND CONCENTRATIONS OF ARCTIC COD

In the Canadian high Arctic, feeding aggregations involving large numbers of marine mammals and piscivorous seabirds are almost all observed in late August-early September (Table 41), a period during which Arctic cod are known to concentrate in dense schools in nearshore waters (Klumov 1937; Ponomarenko 1968; Bain and Sekerak 1978; Craig et al. 1982; Craig and Schmidt 1985). Klumov (1937) called the inshore movement a 'pre-spawning migration' and noted the importance of this event to the movements of marine mammals (ringed, bearded and harp seals, narwhals and white whales) in the Kara and Barents seas; he stated that 'when in these concentrations, the Arctic cod is the primary and, it may be, the only object of feeding of the marine mammals and of other vertebrates'. Klumov (1937) noted that the Arctic cod was absent in the East Siberian Sea but that it was present in the Chukchi Sea and Bering Strait 'where it forms mass concentrations'. Large inshore movements of Arctic cod have also been observed occasionally in the Beaufort Sea (Craig et al. 1982).

Feeding aggregations are usually highly conspicuous events and aggregations of marine mammals in the Canadian Arctic archipelago may indicate that certain areas are important in the life history of the Arctic cod. Documentation of the extent and nature of the feeding aggregations provides an indirect synopsis of the geographical extent and nature of the inshore movement by Arctic cod (Table 41). Analyses of the stomach contents of the predators obtained in late summer provide information about the population structure of the Arctic cod involved in the inshore movement.

Feeding aggregations almost always involve the three migratory species of marine mammals, harp seals, narwhals and white whales, often in association with fulmars, kittiwakes and other larids. These three species of marine mammals appear to freely intermix when feeding on cod and it is apparent from the numbers of mammals involved that large numbers of Arctic cod are required to sustain them. Although ringed seals sometimes form loose aggregations when feeding on concentrations of Arctic cod (Finley et al. 1983b), ringed seals are seldom seen in close association with the other species during feeding frenzies. Similarly, bearded seals have occasionally been seen near feeding aggregations, for example on 6 September 1977 in Allen Bay, Cornwallis Island (Table 41, Fig. 36), but these seals did not congregate in large numbers or associate closely with the other mammal species (Finley, unpublished data). The highly gregarious and mobile nature of the migratory mammals may be an adaptive advantage for locating and exploiting schooling Arctic cod in late summer. Seabirds, such as fulmars and kittiwakes, undoubtedly derive considerable advantage in associating with the marine mammals. Similar avian-marine mammal feeding associations involving key species of schooling prey have been noted in other areas (Ryder 1957; Harrison 1979).

Marine mammal feeding aggregations in the Arctic have been observed primarily in late August and early September, although they have been observed as early as 30 June along ice edges in Lancaster Sound (Table 41). As individual events, feeding 'frenzies' may last a few hours, although feeding aggregations may occur sporadically in the same general areas over several days; this appears to relate to the highly mobile behaviour of large schools of cod. Craig et al. (1982) and Craig and Schmidt (1985) observed highly erratic daily catches of cod in fyke nets in late August.

Except for the fact that feeding aggregations of marine mammals almost always occur in nearshore areas during the open-water season, we cannot discern any particular physical feature associated with the concentrations of Arctic cod. Feeding aggregations occur beneath or near ice, and where waters are mostly ice free. They occur both in shallow bays or around the mouths of deep fiords. They may be predictable or unpredictable in their occurrence in a particular area from year to year. For example, in 1976, Arctic cod were especially abundant in Creswell Bay (Somerset Island) and unusual concentrations of marine mammals and seabirds occurred there (Finley and Johnston 1977). Thousands of cod were washed up on shore and the stomachs of both narwhals and ringed seals were full of cod (Table 41). Also, the sea-run Arctic char in Creswell Bay in 1976 had fed heavily on cod and had acquired a poor taste relative to the years when the char fed primarily on crustaceans (Idlout, Union River, Somerset Island, pers. comm.; Finley, unpublished data). In the summers of 1975 and 1977, Arctic cod were not noted in the area, char fed on crustaceans (Finley, unpublished data), and feeding concentrations of seabirds and marine mammals were absent. A decline in the relative abundance of Arctic cod was noted in the diets of predators in Eclipse Sound between 1978 and 1979 (Finley and Gibb 1982, in press; Bradstreet and Finley 1983). In contrast, Arctic cod appear to occur regularly in some areas (e.g. Allen Bay along Cornwallis Island; Bethune Inlet along Devon Island; Grise Fiord along Ellesmere Island), as evident from the predictability of feeding aggregations of marine mammals in these areas during late summer (Table 41).

Otoliths obtained from stomachs of marine mammals taken in close proximity to feeding aggregations have shown a close relationship between the size of cod ingested and the size of cod available (Finley and Gibb, in press). In most cases the otoliths represented the size range of large (>10 cm) fish. However, in at least one situation it was apparent that the predators were feeding intensively on a narrow size range of small fish. This occurred in Eclipse Sound in late August-early September 1978 when harp seals drove a huge school of small cod into shallow water. Fish dip-netted from the school were the same size (8.2 ± s.d. 0.7 cm fork length, n = 328) as those (8.2 ± s.d. 0.5 cm, n = 23) taken from the stomach of an adult harp seal that had glutted itself. Unusually large numbers of ringed seals had been seen in the surrounding area during the same period and their stomachs also contained large numbers of small cod (see below).

BEHAVIOUR OF ARCTIC COD IN RELATION TO PREDATION

Often during or in the aftermath of feeding frenzies, large numbers of dead or debilitated Arctic cod have been found nearby (Table 41). For example, on 28 August 1976, a huge feeding aggregation of marine mammals and seabirds was observed from the air at Creswell Bay (Table 41); later, thousands of Arctic cod were found dead and stranded over several hundred metres of beach and the adjacent waters were covered with an oil film (Finley and Johnston 1977).

On another occasion (23 August 1979) at Grise Fiord, thousands of Arctic cod were found debilitated after a feeding foray by harp seals. Finley and Gibb (in press) suggest that the cod had been forced from deeper depths and had lost buoyancy control; floating on the surface, they attracted a large feeding aggregation of seabirds. Given the sudden surfeit of food, it was interesting to note that many of the seabirds (kittiwakes and fulmars) were feeding selectively on the livers of the cod, leaving the bodies intact. Arctic cod livers have high fat content (Yudanov 1964). Following this, an extensive oil film formed on the surface. These films of oil have occasionally been detected among feeding aggregations of marine mammals during aerial surveys (Finley, unpublished data).

Following synchronized feeding by harp seals near Kounuk (Eclipse Sound) on 27 August 1978, Arctic cod formed a continuous dense school that extended for several hundred metres along a gently sloping shoreline. The school was 5 to 10 m wide, 1 to 3 m deep and moved like a single body in a sinuous fashion. Individuals within the school showed little or no evasive behaviour when presented with obstacles; several hundred were easily dip netted from the school in a single net pass. Dense schooling is a well-known reaction of fish to predation (Burgess and Shaw 1979).

Arctic cod also appear to use ice as protection from predators. For example, on 12 August 1976 large numbers of seabirds and marine mammals were feeding on Arctic cod beneath the fast ice that still remained in a small bay on Cornwallis Island. Throughout August, cod were found in large numbers in narrow ice cracks, where they were inaccessible to the predators. It is well known to the Inuit that, just prior to break-up, small Arctic cod can be found in considerable numbers in narrow ice cracks. It is uncertain whether this is merely a response to predation or also a reflection of habitat preference by small fish.

SIZES OF ARCTIC COD EATEN BY MARINE MAMMAL PREDATORS

We were unable to demonstrate differences among predators in the ages of cod taken (see above). But we have demonstrated significant differences in the growth of Arctic cod from time to time and/or place to place. If the Arctic cod is a schooling fish, as some evidence and a few observations suggest, cod of similar sizes, and not necessarily similar ages, probably group together. In this section of the report, we examine the sizes of cod (based on otolith lengths) eaten by various marine mammal predators. Generally, there are good relationships between otolith length and fish (fork) length (see above) but in extreme cases otoliths of a given size can represent fish of four different age classes (Fig. 37).

Intraspecific differences in size selectivity

Age: Where possible we looked for differences in size selectivity of Arctic cod by age of predator (Fig. 38 for ringed seals; Fig. 39 for harp seals) but found no significant differences (Kolmogorov-Smirnov $P>0.1$ in 17 comparisons). Similarly, Finley and Gibb (1982) found no significant differences in the mean lengths of cod taken by adult and immature narwhals. This would suggest that Arctic cod are not depth-segregated by size (at least within the diving ranges of the mammals studied).

Season: Since Inuit hunting localities change with season, it is sometimes difficult to separate seasonal from locational differences in size distributions of Arctic cod. When location and age effects could be controlled, which was possible only for ringed seals, we found little evidence of seasonal differences in the sizes of cod ingested (Fig. 40; $P>0.1$ in 14 of 15 comparisons; $P<0.05$ in comparison of otoliths in juvenile seals at Grise during early winter 1978 vs haul out 1979). Finley and Gibb (1982) found no marked seasonal change in the size of Arctic cod ingested by narwhals, although they found a marginally significant ($P<0.05$) decrease in the size of otoliths taken as the narwhals moved from the Pond Inlet ice edge westward into the inlet via ice cracks during break-up.

Year: Where comparisons were possible, we found no significant differences in the sizes of Arctic cod ingested in the same area from year to year (all $P>0.1$). Narwhals consumed the same size of cod at the Pond Inlet ice edge in 1978 and 1979 (Fig. 41), even though the abundance of cod apparently changed between the two years (Finley and Gibb 1982; in press). Harp seals fed on the same size cod in Grise Fiord in the open-water season during the same two years (Fig. 39) even though there was a significant decrease in the number of cod eaten between the two years (Finley and Gibb in press). There was no statistically significant difference in the size of Arctic cod taken by juvenile ringed seals at Grise Fiord in the early winters of 1978 and 1979 (Fig. 40), even though, on average, the seals took fewer cod in 1979 (Bradstreet and Finley 1983).

Although Arctic cod declined in the diets of several predators between 1978 and 1979, we could not discern any changes in the size or age structure of the cod that might indicate that the decline was due to a year class failure. In accounting for the variable distribution and movements of white whales, Kleinenberg et al. (1964) suggested that these changes were related to the strength of year classes of Arctic cod and their movement into nearshore areas.

Area: We compared the size composition of Arctic cod taken in different locations by ringed seals (Fig. 42), bearded seals (Fig. 43), harp seals (Fig. 39) and narwhals (Fig. 41) but found no statistically significant results ($P>0.1$ in 18 of 19 comparisons) when possibly confounding effects (age, season, year) could be controlled. We found one marginally-significant difference (bearded seal, Grise vs Labrador, $P = 0.05$).

Interspecific differences in size selectivity

We compared size distributions of Arctic cod taken by different predators while potentially confounding factors were controlled (Fig. 44). Significant differences ($P<0.01$) were found in two of six comparisons (white whales vs harp seals at Grise Fiord during the open-water season, 1978, and harp seals vs ringed seals at Pond Inlet during the open-water season, 1978). Given the lack of statistically significant differences with respect to predator age, season, and location (see above), we also combined all data for a given predator on a regional basis. Predators at Grise Fiord (ringed seal, bearded seal, harp seal) were taking cod of larger mean otolith lengths than were predators at Pond Inlet (Fig. 45; Table 42). Differences in the size composition of ingested cod were, however, only significant for ringed seals ($P<0.01$).

The frequency distributions of otolith sizes of cod consumed by the five species of marine mammals were very similar (Fig. 45); mean lengths of otoliths ingested by various predators ranged from 4.0 ± s.d. 1.3 mm (ringed seals, all Pond Inlet areas combined) to 6.6 ± s.d. 1.2 mm (bearded seals, Grise Fiord). Apparently, all predator species were eating cod of all sizes up to the maximum size ever found (otolith size of about 11 mm) but cod with otoliths <2 mm were rare or absent in the predators' diets.

Variation in the sizes of cod taken by seals

Although marine mammals occasionally glut themselves when they encounter large schools of Arctic cod in late summer, stomach contents of ringed seals suggest that during most of the year Arctic cod are widely dispersed. Predators that fed heavily (presumably on dense schools) usually contained large numbers of intact fish or remains in a similar state of digestion. However, most ringed seals contained few intact fish, large numbers of otoliths, and bodies in various stages of decomposition.

Assuming that seals taken in close proximity to schools of Arctic cod would more likely be glutted, coefficients of variation of the sizes of otoliths in a stomach were compared with the number of otoliths found in that stomach. There was no indication that variation in the sizes of cod eaten by ringed or harp seals changed as the numbers of cod ingested increased (Table 43). In a second type of analysis, length-frequency distributions of cod otoliths in ringed seal stomachs with varying amounts of food and numbers of otoliths were compared (Fig. 46). No significant differences in the length frequency distributions of otoliths were found among stomachs with differing amounts of food or differing numbers of otoliths ($P>0.1$ in 10 comparisons), but sample sizes were small. Seals were apparently not seeking large schools of Arctic cod of a particular size range in a particular season or place.

Coefficients of variation of the size of otoliths in a ringed seal stomach vs the mean size of otoliths in that stomach were plotted for samples taken during the open-water season at Pond Inlet in 1978. Widely varying coefficients of variation occurred in those stomachs containing small and moderately-sized otoliths (Fig. 47). Variation seemed to decrease in stomachs that contained large otoliths. This could mean that ringed seals selected larger cod when they found them in schools of mixed-sized individuals or that large cod formed discrete schools of similar-sized individuals. The fact that small coefficients of variation occurred in some stomachs containing small otoliths also suggests occasional schooling of similar-sized individuals, since if larger cod had been present in such situations, the indication is that the seals would have eaten them. Large coefficients of variation for some stomachs containing small otoliths and most stomachs containing moderately-sized otoliths suggest that cod almost certainly occur in schools of mixed-sized individuals, too.

In conclusion, we found that marine mammals are excellent sampling agents for Arctic cod; five species that occur in the eastern Canadian Arctic all eat large numbers of this fish.

The distributions of the three migratory mammals (harp seal, narwhal, white whale) and analyses of their diets demonstrate that, during late summer, there is a major movement of Arctic cod into nearshore Arctic waters. In some places (e.g. Allen Bay, Cornwallis Island; Bethune Inlet, Devon Island; Grise Fiord, Ellesmere Island) aggregations of the three migratory mammals and presumed concentrations of cod occur annually; in others (e.g. Eclipse Sound; Creswell Bay, Somerset Island) such aggregations occur sporadically. It appears, therefore, that during the late summer months in the eastern Canadian Arctic, the distribution of Arctic cod can have profound effects on the distribution of harp seals, narwhals and white whales.

While the three migratory species are highly dependent on concentrations of Arctic cod for a short time, ringed seals depend on Arctic cod throughout the year. The widespread distribution of the ringed seal implies that, during most of the year, Arctic cod are abundant in the protected waters of the eastern Canadian Arctic. (During the one season when ringed seal diet has been studied in offshore waters, the haul out period in spring, cod were not important in the diet.) Ringed seals ate larger, older cod at Grise Fiord than at Pond Inlet, and cod of a given age were generally larger in samples from ringed seals taken at Grise than at Pond. This implies that there may be regional differences in environmental conditions affecting Arctic cod growth. We have also demonstrated year effects in growth: otolith lengths-at-age differed between years at Grise and Pond--ice edge.

It appears, therefore, that large-scale geographic and temporal variability in certain characteristics of Arctic cod populations can be measured using otolith material available in marine mammal samples. Given the strong dependence of marine mammals on Arctic cod, it also appears that the distributions of marine mammals can give us much information about the large-scale distribution of Arctic cod.

CONCLUSIONS AND IMPLICATIONS

The Arctic cod is a widespread and abundant fish in the North American Arctic. Current data suggest that Arctic cod are more or less continuously distributed from the northern Bering Sea north and eastward around the continent and southward to the Labrador Sea and northwest Atlantic.

Young-of-the-year Arctic cod appear to be most abundant in the eastern Arctic, especially in the upper 50 m of inshore waters. The dietary analyses of Y-O-Y Arctic cod showed that copepods constituted the major portion of the diet across the entire study region (i.e. from 86 to 99.9% of the food items consumed). In all locations, the smaller life stages (i.e. eggs, nauplii and copepodites) formed the bulk of the diet but as Y-O-Y Arctic cod grew in length the mean size of the food items they consumed also increased. The major copepod species consumed varied within region, by date and depth and among regions which suggest that Y-O-Y Arctic cod fed on locally abundant species and were not dependent on any particular species or group. This ability to consume a wide range of copepod species in a variety of habitats also provides a mechanism that could enhance the dispersal of Y-O-Y Arctic cod.

Juveniles and adult cod are found in both dispersed and concentrated forms. It is unknown whether dispersed fish aggregate at a particular point in their life cycle, but there are yearly late-summer movements into nearshore waters. This could be caused by a behaviour pattern related to the life-history of Arctic cod, or to different behaviour of different stocks of cod or to a combination of the two. The whole question of stock identification in Arctic cod needs attention. Several results from this study indicate the distinct possibility of different stocks, but the subject of distinct stocks of Arctic cod, either remaining separate in different regions or mingling for part of the year, or their life cycle, has not been formally addressed in this work. Yet the presence of distinct stocks when considering the broad range of Arctic cod in the North American Arctic, appears to be a certainty.

European and Soviet researchers have long been aware of the probable existence of many different stocks or semi-discrete populations of Arctic cod. The delineation of Arctic cod stocks and at least some of their specific biological characteristics in North America is an important task for future studies. If such knowledge were available, reasons for variations in age structure, growth and other important factors would be more readily apparent.

Otoliths were better than scales for ageing Arctic cod. The pattern of outer hyaline layer (annular ring) deposition in Arctic cod was investigated in otoliths collected over a continuous 12 month period. In younger fish the annular ring was deposited earlier than in older (age 3+) fish; in all cohorts the thickness of hyaline material peaked but once a year; and in each age group the thickness of opaque material increased with time, being greatest just before the annular mark was laid down and least immediately thereafter. The number of hyaline layers on an Arctic cod otolith is an accurate estimate of fish age.

Many vertebrates valued by man are highly dependent on Arctic cod as food and for some there is simply no acceptable, alternative food supply in terms of availability and energy value. In Lancaster Sound and western Baffin Bay, LGL Limited (1983) found that Arctic cod accounted for 52% of the food consumed by marine birds and mammals and that the cod themselves were the major vertebrate consumers in the study area. Consumption by cod was at least 20 times greater than that by all marine mammals and birds combined. Thus, Arctic cod were the major link in the transfer of energy from lower to higher trophic levels. It seems likely that cod are of similar importance in other Arctic marine areas.

Given the immense importance of Arctic cod, we need to understand as much as possible about the biology of this fish. This is necessary because of the significant role that cod predators play in the economy and lifestyle of northern residents, and because proposed industrial developments in the North may have negative effects on natural marine ecosystems. Monitoring certain aspects of the biology of Arctic cod may, therefore, be an appropriate and relatively inexpensive way to monitor natural or man-induced changes in a large ecosystem.

In this study, we found that collection of otoliths from predator samples (stomachs, feces) allowed us to learn much about the biology of Arctic cod. Careful selection of predator samples allowed us to demonstrate that there were few differences in the age distributions of otoliths due to the age of the predator or the amount of food in its stomach, or due to the habitat or season in which the predator was collected. When such variables were controlled, we also found little evidence of differences due to area or year of collection. But when samples were grouped, there was evidence of large-scale geographical and temporal differences in age-frequency distributions of otoliths. We also found evidence of regional and year-to-year differences in the growth of otoliths; these differences were reliably related to growth in whole Arctic cod. We were also able to calculate estimates of cod mortality based on the otoliths found in predator samples.

The kinds of information that can be determined from otoliths found in predator samples are of use in monitoring changes in Arctic cod populations over space and time. For example, we found differences in the lengths-at-age of otoliths collected at Grise Fiord and Pond Inlet. This suggests that spatial differences in environmental conditions affect cod growth. We also found differences in otolith length-at-age within a region due to year effects, suggesting that there is variability over time in the conditions that promote cod growth. Neither of these results is surprising in a natural ecosystem. But our results indicate that it should be feasible, through the collection of appropriate predator samples over wide areas and several years, to gain an accurate appreciation of the range of natural variability in Arctic cod growth. It is only when the range of natural variability in a population characteristic is understood that the effects of man-induced perturbations can be properly addressed. In addition to information on variability in cod growth, collection of otoliths from predator samples would also give information on variability in other population characteristics of Arctic cod (e.g. age structure and mortality).

One of the constraints of the present study was that stomach and fecal samples were collected in order to study cod predators, not the Arctic cod themselves. Therefore, sample collection was not always structured in a way that facilitated certain analyses. Nevertheless, the fact that we were able to demonstrate spatial and temporal differences in certain population characteristics of Arctic cod indicates that a sampling scheme designed to provide specific information about Arctic cod would be successful. The proper design of such a sampling scheme is of critical importance to such an undertaking.

We recommend that such a sampling scheme focus on a single predator species, the ringed seal, which is a common and widespread marine mammal in the North American Arctic. Ringed seals are widely harvested by northern residents, throughout the year. Data presented in Davis et al. (1980) show that ringed seals are taken in large numbers (46,000 in 42 communities in 1976) across northern Canada. Ringed seals seem to feed on Arctic cod if they are present within the seals' foraging range (Lowry et al. 1980a; Bradstreet and Finley 1983). Therefore, widespread collection of ringed seal stomachs would provide information on the geographic distribution of cod, year-round.

Ringed seals are a major consumer of Arctic cod. In Lancaster Sound and western Baffin Bay, LGL Limited (1983) found that ringed seals consumed more Arctic cod than did all other marine mammal and seabird species combined. Since large numbers of cod otoliths were often found in the stomachs of ringed seals analyzed during this study, the widespread collection of ringed seal samples will almost certainly provide large numbers of Arctic cod otoliths for analysis. Ringed seals also seem to eat cod of all ages (except young-of-the-year). Thus, large portions of the age and size ranges of Arctic cod present in an area are likely to be represented in collections of seal stomachs.

Since ringed seals are widely harvested by northern residents, sample collection should be feasible with modest expenditure. The opportunity to involve local people in monitoring the health of the marine environment on which they depend is also an important consideration in selecting the ringed seal as a sampling agent for Arctic cod. Other marine mammal species are either not as widely distributed or harvested as are ringed seals or are not present throughout the year. Seabirds are infrequently harvested by northern residents and seabird samples analyzed during this study either contained few otoliths (northern fulmar) or numbers of large, broken unusable otoliths (thick-billed murre).

The number of ringed seal samples necessary to monitor certain population characteristics need not be large; 25 samples from a community in each year of study would provide enough otoliths for credible comparisons. But the number of communities sampled should be fairly large (20-25) and the study should extend over several years (five or more) in order that natural variability or trends in population characteristics can be ascertained. It would be ideal if only full seal stomachs from only certain times of the year and certain specified hunting areas were collected. However, this might prove difficult to administer, and results from this study indicate that such restrictions may not be important. Nevertheless, there seems to be little point in collecting samples with so little material that they cannot be used. Only seal stomachs whose contents are above a certain minimum weight (250 g) should be analysed.

On balance, collection of ringed seal stomachs from many communities over several years seems to be a feasible means of collecting large numbers of Arctic cod otoliths. These otoliths can then be used to monitor spatial and temporal variability in the age structure, growth and mortality of Arctic cod.

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Table 1. Recently-available estimates of mean densities of Y-O-Y cod in the North American Arctic and Subarctic[a].

Area	Depth range sampled (m)	Collection method	No. of samples	Dates	Density (no./100 m^3)	Source
SE Baffin Island off Frobisher Bay						
1-10 km offshore	0-60	1.0 m Bongo tows	32	mid Aug to early Sep 1978	0.25	Den Beste and McCart 1978
1-10 km offshore	10-70	Isaacs-Kidd mid-water trawl	8	mid Aug to early Sep 1978	0.02	Den Beste and McCart 1978
Bays and Fiords	0-5	1.0 m single Stramen trawl	11	mid Aug to early Sep 1978	0.30	Den Beste and McCart 1978
Labrador Sea						
Bays and Fiords	0-125	Double oblique Bongo tows	153	early Aug to early Sep 1979	33.93	Buchanan and Foy 1980
Nachvak Fiord, NE Labrador	0-10	Faber net	?	Jul to Aug 1978	65.0	Den Beste and McCart 1979
Offshore S Labrador	?	Acoustic survey	940 km	mid Oct 1978	1.8	Miller 1979
Offshore NE Newfoundland	?	Acoustic survey	620 km	12-14 Oct 1978	66.7	Miller 1979
Offshore NE Newfoundland	?	Acoustic survey	540 km	20-21 Oct 1978	110.5	Miller 1979

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[a] Data presented in this table supplement the more extensive results published by Sekerak (1982b). All densities are means of depth-weighted averages. All samplers were towed horizontally except in the Labrador Sea. Data of Miller (1979) expressed as cod/m^2 were recalculated as densities in the upper 50 m.

Table 2. Abundance of dispersed Arctic cod (other than Y-O-Y) in North American arctic waters.

Area	Depths sampled (m)	Collection method	No. of samples	Estimated mean abundance per 30 min trawl		Source
				No. of cod	Wt (kg)	
NE Bering Sea	<50	Otter trawl 5.8 m head rope	32	5.1	-	Lowry and Frost 1981
NE Bering Sea	15-65	Otter trawl 27.7 m head rope	100		0.7	Pereyra and Wolotira 1977
SE Chukchi Sea	15-65	Otter trawl 27.7 m head rope	100		0.9	Pereyra and Wolotira 1977
NE Chukchi Sea	40-123	Otter trawl 5.8 m head rope	10	30.9		Lowry and Frost 1981
NE Chukchi Sea	7-14	Otter trawl 3.7 m gap	6	9.5		Fechhelm et al. 1984
NE Chukchi Sea	15-48	Otter trawl 7.6 m gap	19	275.6		Fechhelm et al. 1984
W Beaufort Sea (Barrow to Prudhoe)	40-400	Otter trawl 5.8 m head rope	8	23.4		Lowry and Frost 1981
Central Beaufort Sea (Prudhoe to Int. border)	50-150	Otter trawl 5.8 m head rope	15	5.7		Lowry and Frost 1981
E Hudson Strait		Sputnic 1600 shrimp trawl 43 m head rope	10	110	1.9[a]	MacLaren Marex Inc. 1978
E Hudson Strait	218-486	Sputnic 1600 shrimp trawl	27	103[b]	2.1[a]	Imaqpik Fisheries Inc. 1981
Ungava Bay		Sputnic 1600 shrimp trawl 43 m head rope	8	1143[b]	23.2[a]	MacLaren Marex Inc. 1978
Ungava Bay	161-530	Sputnic 1600 shrimp trawl	66	227[b]	4.6[a]	Imaqpik Fisheries Inc. 1981
Central-N Ungava Bay	118-611	Lofoten exploratory trawl	23	145[a]	2.9[a]	M. Allard, Makivik Corp., pers. comm.
N Davis Strait		Sputnic 1600 shrimp trawl 43 m head rope	56	143[b]	2.9[a]	MacLaren Marex Inc. 1978

Table 2. Concluded.

Area	Depths sampled (m)	Collection method	No. of samples	Estimated mean abundance per 30 min trawl: No. of cod	Estimated mean abundance per 30 min trawl: Wt (kg)	Source
S Davis Strait		Sputnic 1600 shrimp trawl 43 m head rope	14	15[b]	0.3[a]	MacLaren Marex Inc. 1978
Labrador 1959-1977 52° to 60°30'N	101-850	Yankee trawl 41.5 m	48	17.4[a]	0.6[c]	Lear 1979a
Labrador 1977-1978 52° to 60°30'N	51-1450	164 Engels high rise trawl	61 59	807.9 [a] 42.47[a] [d]	28.3[c] 1.5[c] [d]	Lear 1979a
Newfoundland 1959-1977 46°30' to 52°N	1-800	Yankee trawl 41.5 m	48	17.44[a]	0.5[c]	Lear 1979a
Newfoundland 1977-1978 46°30' to 52°N	51-1400	164 Engels high rise trawl	91	0.06[a]	<0.1[c]	Lear 1979a
South of Newfoundland 1959-1977 42° to 46°30'N	51-850	Yankee trawl 41.5 m	96	0.09[a]	<0.1[c]	Lear 1979a
1977-1978	51-700	164 Engels high rise trawl	36	0.03[a]	<0.1[c]	Lear 1979a
Pond Inlet	0-2	Under-ice SCUBA	60 m viewed	0.5/m^2; under pressure ridge		Bradstreet 1982
			60 m viewed	0.67/m^2; under pressure ridge		Bradstreet 1982
			60 m viewed	0.67/m^2; under pressure ridge		Bradstreet 1982
			80 m viewed	0.12/m^2; under pressure ridge		Bradstreet 1982
			?	<0.01 m^2; under smooth ice		Bradstreet 1982
		Under-ice fyke net	50 fyke net days for both types of ice combined	0.4/trap day; smooth ice		Bradstreet 1982
				1.3/trap day; near rough ice		Bradstreet 1982

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[a] Calculated for present study. Not available in original source.

[b] Calculated from mean weight/individual as 20.3 g for sample of 916 Arctic cod from Ungava Bay (M. Allard, Makivik Corp., pers. comm.).

[c] Calculated from mean weight/individual as 35 g--assuming mean length is 160 mm (Lear 1979a) and using length-weight relationship of Lear (1979b).

[d] Excluding two largest catches.

Table 3. Observations of concentrated schools of Arctic cod in the North American Arctic and adjacent regions.

Area	Date	Description	Reference
Pt. Barrow, Alaska	early Sept 1880's	Large loose schools of full-grown fish swimming along beach in about 6 m of water	Murdoch 1885
	early Oct 1881	Large numbers washed up on beach	Murdoch 1885
Igloolik Island, N of Foxe Basin	early summer 1950's	Great schools of cod in Turton Bay	McLaren 1958
Simpson Lagoon, Beaufort Sea	mid Aug 1978	Large schools in lagoon; over 100,000 captured in fyke nets; estimated abundance 19 million	Craig et al. 1982
Prudhoe Bay, Beaufort Sea	Aug 1978	School of cod about 35 m wide by 300 m long swimming along shoreline; estimated abundance 1-2 million	C. Broad, pers. comm. in Craig et al. 1982
Resolute Bay, Cornwallis Island	July 1976	100s in nearshore ice cracks	Bain and Sekerak 1978
Allen Bay, Cornwallis Island	Aug/Sept 1976	100s in nearshore ice cracks in August, 100s tide stranded (?) in September; loose schools of several 100s observed in fall	Bain and Sekerak 1978
Creswell Bay, Somerset Island	Sept 1976	100s tide stranded (?)	Bain and Sekerak 1978

Table 3. Continued.

Area	Date	Description	Reference
Duke of York Bay, Southampton Island	16 Aug 1821	Great numbers left in pools by the tide	Parry 1824
Batty Bay, Somerset Island	July 1833	Great numbers taken from between cracks in the ice	Ross 1835
Pt. Lay, Chukchi Sea	late July-early Aug 1983	Up to 1435 Arctic cod/fyke net day; large catches sporadic, suggesting schooling	Craig and Schmidt 1985
NE Lancaster Sound	Aug 1978	Small schools (low 10s) of Arctic cod commonly observed in field of pan ice	Sekerak, pers. obs.
NW Ungava Bay	Aug 1978	246 kg or 12,100 Arctic cod in 30 min trawl	MacLaren Marex Inc. 1978
NW Davis Strait	Aug 1978	24 kg or 1200 Arctic cod in 30 min trawl	MacLaren Marex Inc. 1978
Mouth of Pangnirtung Fiord	Aug 1978	Depth sounder recorded large concentration, several 10s of metres thick, of probable Arctic cod	MacLaren Marex Inc. 1978
N Labrador	27 Sept 1978	Sounder recorded large concentrations near bottom at depth 110-140 m, two 30 min trawl catches were 115,785 (13,176 kg) and 19,320 (1958 kg) of Arctic cod	Lear 1979a

Table 3. Concluded.

Area	Date	Description	Reference
Eclipse Sound	late Aug-early Sept 1978	Huge shoal of small cod (80-85 mm long) 'driven' inshore by harp seals	Finley and Gibb, in press
Creswell Bay, Somerset Island	early Sept 1976	1000s Arctic cod stranded on beach; oil slick on water after feeding frenzy by marine mammals	This report
Grise Fiord, Ellesmere Island	23 Aug 1979	1000s Arctic cod debilitated after feeding by harp seals; oil slick observed on water	Finley and Gibb, in press
Assistance Bay, Cornwallis Island	12 Aug 1976	1000s Arctic cod beneath small amount of ice left in bay; seabirds and marine mammals feeding on concentration	This report
Pt. Barrow, Alaska	Feb 1882	Large numbers of Arctic cod caught by jigging between pressure ridges	Murdoch 1885
NW Greenland	Winter 1700's	Arctic cod especially abundant in northern fiords in winter	Fabricius in Jensen 1948
Egedesminde to Upernavik, Greenland	Winter 1850's	Occurs under ice in large schools	Rink 1857 in Jensen 1948
Jakobshavn, Greenland	1850's	Occurs regularly in winter in large numbers; 100s jigged 2-3 m below surface of ice	Rink 1857 in Jensen 1948
N Siberian Sea near Pole	1968-69	Swarms of Arctic cod present from late Nov to Feb in holes in ice	Andriashev et al. 1980

Table 4. Sampling location, date and depth of samples of young-of-the-year Arctic cod used in the diet study.

Region	Date	Number of stomachs	Depth range (m)	Range in mean length (mm)	Type of sampling gear (mesh size)	Reference
Labrador Sea	16 Jul - 6 Sep 1979	207	73 - 603	15.8 - 39.2	0.5 m Bongo (505 µm)	Buchanan and Foy 1980
Northwest Baffin Bay	4 Aug - 11 Sep 1978	86	10 - 50	12.3 - 21.7	Miller sampler (750 µm)	Sekerak et al. 1979
Lancaster Sound	22 Jul - 7 Sep 1976	216	0 - 150	10.2 - 25.82	0.5 m net (239 µm)	Sekerak et al. 1976b
Wellington Channel	13 Jun - 5 Jul 1976	62	ice edge	6.6 - 14.0	0.25 m net (569, 239, 76 µm)	Bain et al. 1977
Brentford Bay, Boothia Pen.	30 Aug - 1 Sep 1977	38	surface	17.6 - 21.8	Dip net	Thomson et al. 1978
Southeastern Beaufort Sea	11 Aug - 25 Aug 1981	99	0 - 30	14.2 - 21.9	0.61 m net (500 µm)	Griffiths and Buchanan 1982

Table 5. Results of the Wilcoxon test comparing percent composition of each food taxon in the diet of young-of-the-year Arctic cod in relation to fish length.

Location	Collection	Size classes (mm)	Wilcoxon z-value	P
Labrador Sea	LA-2 17 Jul	15.59 ± 2.03; 21.86 ± 3.33	1.69	0.09
	LD-1 23 Jul	16.32 ± 1.20; 19.56 ± 0.43	0.48	0.63
	LD-2 24 Jul	17.19 ± 1.27; 20.87 ± 1.81	0.75	0.45
	LD-3 24 Jul	17.48 ± 0.44; 21.35 ± 1.43	1.85	0.06
	LF-1 6 Aug	16.38 ± 1.83; 20.86 ± 1.57	0.85	0.40
Lancaster Sound	NB 26 Jul	8.56 ± 0.90; 13.39 ± 1.84	0.0	1.0
Brentford Bay	BF-111 30 Aug	16.07 ± 1.03; 21.50 ± 1.79	0.56	0.58

Table 6. Percent composition of diets of young-of-the-year Arctic cod collected at different depths at a single station in Lancaster Sound, 22 July 1976.

Depth of sample (m)	0	10	50	150
Number of stomachs	20	20	20	3
Prey items				
ZOOPLANKTON				
Pseudocalanus minutus I/II	0.16	-	3.40	-
III/IV	-	0.16	0.75	1.25
female	-	-	-	1.25
Calanus finmarchicus II	-	-	0.38	-
Calanus glacialis I	0.64	-	5.28	-
II	0.48	-	4.91	-
III	0.32	-	0.38	-
Calanus hyperboreus II	0.16	-	-	-
Oithona similis copep.	3.82	1.14	8.30	1.25
female	-	-	0.75	-
Oncaea borealis	-	-	0.38	-
Calanoid nauplii >0.4 mm	3.02	0.98	3.77	1.25
0.2-0.4 mm	28.62	14.15	28.68	21.53
<0.2 mm	12.88	5.69	13.58	3.80
egg 0.16 mm	42.77	70.41	16.60	63.31
Cyclopoid nauplii 0.2-0.4 mm	0.48	0.49	-	-
<0.2 mm	6.36	4.88	7.92	6.34
egg 0.08 mm	-	0.16	-	-
Bivalve veliger	-	1.46	4.91	-
Limacina helicina veliger 0.2-0.4 mm	-	0.33	-	-
Fritillaria borealis	0.32	-	-	-
PHYTOPLANKTON				
Coscinodiscus	-	0.16	-	-

Table 7. Percent composition of diets of young-of-the-year Arctic cod collected on different dates near Cape Warrender, Devon Island, 1976.

		Date				
		24 July n=20; 10 m	3 August n=20; 10 m	17 August n=13; 10-50 m	27 August n=7; 10-150 m	7 September n=20; 50 m
Mean length (mm)		14.5	13.3	19.7	20.6	25.8
ZOOPLANKTON						
Calanus hyperboreus	I	-	-	-	-	0.33
	II	-	0.44	-	-	0.27
	III	0.14	-	-	-	1.14
	IV	-	-	-	-	0.27
Calanus finmarchicus	II	-	-	-	-	0.07
	III	-	-	-	-	0.13
Calanus glacialis	I	4.04	1.74	2.45	1.22	3.41
	II	0.70	0.22	3.99	2.39	2.21
	III	0.98	0.22	4.95	1.80	1.27
	IV	-	-	1.99	-	0.07
Pseudocalanus minutus	I/II	3.35	3.05	4.95	8.97	27.64
	III/IV	3.49	0.87	11.90	22.76	23.83
	V	0.28	-	1.99	1.22	0.74
	female	-	-	-	-	0.27
Euchaeta glacialis	II	0.14	-	-	-	-
Acartia longiremis	V/adult	-	-	-	-	0.13
Microcalanus		-	-	-	-	0.27
Oithona similis	female	0.56	-	-	1.22	0.20
	male	-	-	-	1.80	0.13
	copepodite	6.83	3.05	3.47	9.60	1.74
Oncaea borealis		1.39	-	-	0.59	0.20
Calanoid nauplii	>0.4 mm	12.83	5.88	1.48	4.19	2.48
	0.2-0.4 mm	26.92	31.37	9.40	10.18	7.30
	<0.2 mm	13.39	13.29	0.51	4.19	1.41
	egg 0.16 mm	10.46	27.02	2.96	-	-
Cyclopoid nauplii	<0.2 mm	3.35	1.53	-	1.22	0.27
	0.2-0.4 mm	6.69	-	-	-	-
	egg 0.08 mm	0.14	-	-	-	-
Harpacticoid adult		-	-	-	-	0.07
	nauplius 0.2-0.4 mm	0.14	-	-	-	-
Cirripede nauplius		-	-	-	-	0.13
Bivalve veliger		0.42	0.44	-	-	0.27
Chaetognath		-	-	-	-	0.07
Polychaete larva		-	-	-	-	0.07
Limacina helicina veliger	>0.4 mm	2.93	-	0.51	-	-
	0.2-0.4 mm	0.70	-	-	-	-
Clione limacina veliger		0.14	-	-	-	-
Fritillaria		-	0.22	4.95	22.12	23.56
PHYTOPLANKTON						
Coscinodiscus spp.		-	0.68	44.53	0.59	-

Table 8. Numbers of young-of-the-year Arctic cod from different depths collected near Cape Warrender, Devon Island, 3 August to 7 September 1976.

Date of collection	Depth of sample 10 m	50 m	150 m
24 July	20	-	-
3 August	20	-	-
17 August	4	9	-
27 August	1	4	2
7 September	-	-	20

Table 9. Overall mean percent composition of stomach contents of young-of-the-year Arctic cod collected from various locations in the Canadian Arctic, 1976-1981.

Location	Labrador Sea	Northwest Baffin Bay	Lancaster Sound	Brentford Bay	Wellington Channel	Southeastern Beaufort Sea
Year	1979	1978	1976	1977	1976	1981
Mean length (mm)	20.3	16.5	15.3	19.7	9.2	19.9
ZOOPLANKTON						
Copepods						
Euchaeta glacialis	-	-	P[a]	0.2	-	-
Calanus finmarchicus	3.7	0.9	0.1	-	-	-
Calanus glacialis	4.7	4.2	5.4	41.6	0.6	1.5
Calanus hyperboreus	0.1	0.4	0.3	0.5	-	1.2
Pseudocalanus minutus	6.2	12.5	11.9	4.7	20.3	26.0
Limnocalanus macrurus	-	-	-	-	-	0.1
Acartia longiremis	0.4	1.5	0.1	27.3	-	-
Derjuginia tolli	-	-	-	-	-	0.2
Eurytemora sp.	-	-	-	-	-	P
Microcalanus sp.	0.2	0.4	P	-	-	-
Oithona similis	11.6	15.1	3.8	2.4	1.6	P
Oithona atlantica	P	-	-	-	-	-
Oncaea borealis	0.1	0.1	0.2	0.3	-	P
Unid. calanoid copepods	30.4	44.4	62.9	21.4	70.3	64.2
Unid. cyclopoid copepods	35.0	5.1	5.1	1.7	5.4	0.7
Unid. harpacticoid copepods	-	-	P	-	-	P
Copepod parts	3.2	1.4	-	-	-	6.0
(Total copepods)	(95.7)	(86.0)	(89.7)	(99.8)	(98.2)	(99.9)
Amphipods	P	-	-	-	-	-
Euphausiids	0.2	-	-	-	-	0.1
Larvaceans	0.9	11.4	4.4	-	-	-
Cirripedes	1.3	-	P	0.3	1.2	-
Pteropods	P	0.6	0.8	-	0.5	-
Bivalve veligers	0.1	0.4	0.6	-	-	-
Polychaete larvae	0.1	-	P	-	-	-
Chaetognaths	P	-	P	-	-	-
Unidentified eggs	1.6	-	-	-	-	-
PHYTOPLANKTON						
Coscinodiscus	P	1.6	4.3	-	-	-
Peridinium	-	-	P	-	-	-

[a] P indicates prey item present in small amounts.

Table 10. Size distributions of taxa constituting >5% of the diet of young-of-the-year Arctic cod collected from various locations in the Canadian Arctic, 1976-1981.[a]

Prey taxa	Life stage	Prey size (mm)	Labrador Sea 1979	Northwest Baffin Bay 1978	Lancaster Sound 1976	Brentford Bay 1977	Wellington Channel 1976	Southeastern Beaufort Sea 1981
ZOOPLANKTON								
Calanus finmarchicus	I	0-1	1.9	-	-	-	-	-
	II	0-1	1.1	-	-	-	-	-
	III	0-1	0.5	-	-	-	-	-
	IV	1-2	0.1	-	-	-	-	-
	male	2-3	P[b]	-	-	-	-	-
	female	2-3	-	-	-	-	-	-
Calanus glacialis	I	0-1	2.6	2.3	2.7	25.9	-	-
	II	1	1.6	1.7	1.8	14.8	-	-
	III	2	0.4	0.2	0.8	0.8	-	-
	IV	2-3	P	P	0.2	0.2	-	-
	V	3-4	P	-	-	-	-	-
Pseudocalanus minutus	I/II	0.25	3.1	7.0	4.9	2.3	-	16.9
	III/IV	1	1.9	5.4	5.2	2.0	-	6.6
	V	1-2	0.6	0.1	0.4	0.3	-	0.3
	male	1-2	P	-	-	-	-	P
	female	1-2.5	0.6	P	0.2	0.2	1.7	2.2
	egg	0.14	-	-	1.2	-	18.6	-
Acartia longiremis	I/II	0.25	-	-	-	20.6	-	-
	III/IV	1	-	-	-	6.0	-	-
	V	2	-	-	-	0.3	-	-
	female	1-2	-	-	-	0.3	-	-
Oithona similis	male	1	0.6	-	0.1	-	-	-
	female	1	4.0	0.6	0.2	-	-	-
	copepodite	0.5	7.0	14.3	3.5	-	1.6	-
	egg	0.4	-	0.1	-	-	-	-
Unid. calanoid copepods	nauplii--large	>0.4	3.3	3.7	5.4	7.2	4.3	7.9
	nauplii--medium	0.2-0.4	15.1	11.4	27.2	9.2	11.9	30.2
	nauplii--small	<0.2	6.4	10.2	9.6	2.4	33.1	6.0
	copepodite	0.5	-	-	-	-	0.8	-
	egg	0.16	5.5	18.8	20.6	-	20.2	20.0
Unid. cyclopoid copepods	nauplii--medium	0.2-0.4	0.3	-	0.8	-	0.2	-
	nauplii--small	<0.2	2.1	5.0	4.3	-	4.8	-
	egg	0.08	32.6	0.1	P	-	0.5	-
Copepod Parts			-	-	-	2.7	-	6.0
Larvaceans			-	-	-	-	-	-
			-	11.4	-	-	-	-
PHYTOPLANKTON								
Coscinodiscus			0.15	-	4.3	-	-	-

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[a] Values in table are overall mean percent composition.
[b] P indicates prey item present in small amounts.

Table 11. Comparison of mean percentages of copepods in the diets of young-of-the-year Arctic cod and the major copepod groups and species from the six sampling areas.

Region, year	Mean percent of copepods in Y-O-Y Arctic cod diets	Major groups or species of copepods consumed	Mean percent of each major group or species
Labrador Sea, 1979	95.7	Calanoid copepods	30.4
		Cyclopoid copepods	35.0
		Pseudocalanus minutus	6.2
		Oithona similis	11.6
		Calanus glacialis	4.7
		Calanus finmarchicus	3.7
Northwest Baffin Bay, 1978	86.0	Calanoid copepods	44.1
		Cyclopoid copepods	5.1
		Pseudocalanus minutus	12.5
		Oithona similis	15.1
		Calanus glacialis	4.2
		Acartia longiremis	1.5
Lancaster Sound, 1976	89.7	Calanoid copepods	62.9
		Cyclopoid copepods	5.1
		Oithona similis	3.8
		Pseudocalanus minutus	11.9
		Calanus glacialis	5.4
Brentford Bay, 1977	99.8	Calanoid copepods	18.8
		Calanus glacialis	41.6
		Pseudocalanus minutus	4.7
		Oithona similis	2.4
		Acartia longiremis	27.3
Wellington Channel, 1976	98.2	Calanoid copepods	70.3
		Pseudocalanus minutus	20.3
Southeastern Beaufort Sea, 1981	99.9	Calanoid copepods	64.2
		Pseudocalanus minutus	26.0
		Calanus glacialis	1.5

Table 12. Comparison of diets of Y-O-Y Arctic cod from the present study with those of juvenile and adult Arctic cod from the North American Arctic.

	Juveniles and Adults													Y-O-Y
	Lowry and Frost 1981[a]	Fechhelm et al. 1984[b]		Lowry and Frost 1981[a]	Craig et al. 1982[b]					Bain and Sekerak 1978[b]		Bradstreet and Cross 1982[c]		Present Study[d]
Location	Bering Sea	Chukchi Sea		Chukchi/Beaufort seas	Simpson Lagoon					Cornwallis Island		Pond Inlet ice edge		Canadian Arctic
	Summer	Winter	Summer	Summer	Summer			Winter		Resolute Bay	Allen Bay	Inshore	Offshore	Summer
Year	1977	1983	1983	1977	1977	1978	1979	1978-79	1979-80	1976	1976	1979	1979	1976-1980
Mean fish length (range) in mm	147	65	110	88	160	109	92	125	92	(47-200+)	(101-200+)	111	80	(9.2 to 20.5)
Mysids	19.2	7.5	10.8	8.9	87	59	59	93	-	8.1	1.3	2.9	5.2	-
Amphipods	68.4-79.3	7.5	24.9	61.8-72.0	10	17	41	2	17	91.6	81.5	36.1	21.7	-
Copepods	-	85.0	51.1	70.1	2	44	1	-	22	0.4	7.5	61.0	72.8	94.8
Euphausiids	-	-	-	5.2	1	-	-	-	3	-	-	-	-	0.1
Larvaceans	-	-	-	-	-	-	-	-	-	-	-	-	-	2.7
Decapods	27.4	-	4.8	1.9	-	-	-	-	-	-	<0.1	-	-	-
Cirripedes	-	-	-	-	-	-	-	-	-	-	-	-	-	0.5
Chaetognaths	-	-	0.1	-	-	-	-	-	-	-	-	<0.1	-	-
Pteropods	-	-	-	4.5	-	-	-	-	-	-	1.1	-	-	0.5
Cumaceans	1.4	-	17.4	-	-	-	-	-	1	-	-	-	-	-
Bivalve veligers	-	-	-	-	-	-	-	-	-	-	-	-	-	0.2
Fish	5.5	-	6.9	-	-	-	-	2	59	-	8.7	-	-	-
Phytoplankton	-	-	-	-	-	-	-	-	-	-	-	-	-	1.0
Miscellaneous	2.7	-	4.0	-	-	-	-	2	-	<0.1	<0.1	-	<0.1	-

[a] Values are frequency of occurrence (%).
[b] Values are % composition (wet weight).
[c] Values are % composition (dry weight).
[d] Values are % composition (number of items).

Table 13. Numbers and sources of Arctic cod otoliths aged in this study.

Type of sample	No. samples	No. otoliths
Narwhal stomachs	27	607
White whale stomachs	10	250
Bearded seal stomachs	23	495
Harp seal stomachs	29	648
Ringed seal stomachs/feces	256	7188
Northern fulmar stomachs	24	68
Thick-billed murre stomachs	296	2362
Whole Arctic cod	952	952
Totals	665 predator samples 952 whole cod	12,570 otoliths

Table 14. Comparisons among three methods of ageing Arctic cod otoliths.

Comparison	Number of otoliths (% of total) Ground	Burned
Age equal to that determined by external viewing	129 (96.3)	100 (82.6)
Age greater than that determined by external viewing by 1 yr	4 (3.0)	15 (12.4)
Age less than that determined by external viewing by 1 yr	1 (0.7)	6 (5.0)
Total	134 (100.0)	121 (100.0)

Table 15. Within- and among-observer variability in ageing Arctic cod otoliths (n = 100 otoliths in all comparisons).

Comparison	Friedman Statistic	Probability
Otolith ages determined in each of three trials by single observer	Observer 1 S' = 8.088 Observer 2 S' = 2.800 Observer 3 S' = 3.211	$P<0.02$ $P>0.1$ $P>0.1$
Mean difference in ages determined in three trials[a]	Observer 1 vs 2 vs 3 S' = 21.245	$P<0.001$
Maximum age - minimum age determined in three trials	Observer 1 vs 2 vs 3 S' = 15.617	$P<0.001$

[a] For each observer, mean difference = $(ABS(A_1-A_2)+ABS(A_1-A_3)+ABS(A_2-A_3))/3$, where ABS = absolute value and A_1, A_2 and A_3 are the ages determined in trials 1, 2 and 3, respectively.

Table 16. Distance between distal edge of outer annular ring and total otolith length in three cohorts of Arctic cod obtained at Pond Inlet in 1978 and 1979. Data are mean ± s.d. (n).

		1977 Cohort		1976 Cohort		1975 Cohort	
		1+	2+	2+	3+	3+	4+
1978	June	0.70 ± 0.177 (15)	-	0.30 ± 0.146 (15)	-	0.38 ± 0.157 (11)	-
	July	0.65 ± 0.264 (15)	-	0.55 ± 0.304 (15)	-	0.15 ± 0.084 (12)	-
	August	0.73 ± 0.260 (15)	-	0.59 ± 0.175 (15)	-	0.44 ± 0.135 (15)	-
	September	0.93 ± 0.154 (15)	-	0.86 ± 0.375 (14)	-	0.39 ± 0.203 (15)	-
	October	-	0.18 ± 0.096 (4)	0.70 ± 0.231 (10)	-	0.67 ± 0.176 (15)	-
	November	1.20 ± 0.141 (2)	0.18 ± 0.050 (4)	0.99 ± 0.227 (12)	-	0.66 ± 0.241 (15)	-
	December	-	0.20 ± 0.071 (5)	1.15 ± 0.389 (6)	0.08 ± 0.029 (3)	0.63 ± 0.189 (7)	0.25 ± 0.071 (2)
1979	January	-	0.15 ± 0.058 (4)	-	0.20 ± 0.100 (3)	0.40 ± 0.000 (2)	-
	February	-	0.35 ± 0.100 (4)	-	0.15 ± 0.087 (3)	-	0.25 ± 0.212 (2)
	March	-	0.34 ± 0.160 (8)	-	0.19 ± 0.145 (10)	1.2 (1)	0.20 (1)
	April	-	0.33 ± 0.258 (6)	-	0.23 ± 0.058 (3)	-	0.15 ± 0.071 (2)
	May	-	0.47 ± 0.183 (10)	-	0.11 ± 0.039 (9)	0.55 ± 0.071 (2)	0.1 ± 0.000 (3)

Table 17. Between-observer variability in three measures of annular growth in Arctic cod otoliths.

	Type of annular growth measurement[a]		
	Centre of centrum anterior	Centre of centrum posterior	Ring-to-ring
Number of cases	190	174	189
Estimated variability ($\bar{x}$ ± s.d.)			
Observer 1	0.030 ± 0.049	0.037 ± 0.070	0.022 ± 0.048
Observer 2	0.025 ± 0.050	0.035 ± 0.094	0.020 ± 0.031
Wilcoxon P	0.15	0.22	0.10

[a] Refer to Fig. 11.

Table 18. Comparison of ring-to-ring and centrum-ventral measurements (mm) in Arctic cod otoliths.

		Mean ± s.d.	
Age	N	Ring-to-ring measurements	Centrum-ventral measurements
5+	20	8.1 ± 0.6	1.3 ± 0.2
4+	40	7.1 ± 0.6	1.2 ± 0.2
3+	60	5.8 ± 0.7	1.0 ± 0.2
2+	80	4.1 ± 0.4	0.8 ± 0.1
1+	100	1.6 ± 0.3	0.3 ± 0.1

Table 19. Otoliths measured for length differences at different annular rings.

Otoliths from:	Location	Date(s) collected	Year	No. measured
94 whole cod	Pond Inlet ice edge	16 May-2 July	1979	94
35 whole cod	Button Point, Bylot Island	17 July	1978	35
4 narwhal stomachs	Pond Inlet	23-27 August	1979	13
46 whole cod	Tremblay Sound	18 August	1978	46
89 whole cod	Resolute Bay	29-30 August	1977	89
100 whole cod	Resolute Bay	9-13 August	1976	100
3 harp seal stomachs	Resolute Bay	? September	1977	100
100 whole cod	Resolute Bay	8-26 September	1976	100

Table 20. Statistical comparisons of corresponding annular growth rings in Arctic cod otoliths obtained in different years.

Groups compared		Age compared		Annular ring compared		Ring-to-ring measurement $[\bar{x} \pm SD\ (n)]$		t	P
A	B	A	B	A	B	A	B		
Arctic cod, Pond Inlet 1979	Arctic cod, Pond Inlet 1978	5+	4+	4	4	7.500 ± 1.697 (2)	5.267 ± 0.473 (3)	2.323	ns
		4+	3+	3	3	4.450 ± 0.495 (2)	4.388 ± 0.352 (8)	0.210	ns
		3+	2+	2	2	3.427 ± 0.526 (33)	3.561 ± 0.441 (18)	-0.918	ns
		2+	1+	1	1	1.429 ± 0.349 (42)	1.617 ± 0.172 (6)	-1.288	ns
Narwhal, Pond Inlet 1979	Arctic cod, Tremblay Sound 1978	2+	1+	1	1	1.557 ± 0.223 (7)	1.752 ± 0.343 (27)	-1.419	ns
Arctic cod, Resolute 1977	Arctic cod, Resolute 1976	5+	4+	4	4	7.011 ± 0.917 (9)	6.033 ± 0.644 (45)	3.865	<0.01
		4+	3+	3	3	5.533 ± 0.784 (45)	5.293 ± 0.679 (29)	1.350	ns
Harp seal, Resolute 1977	Arctic cod, Resolute 1976	5+	4+	4	4	5.533 ± 0.666 (3)	6.427 ± 0.743 (48)	-2.030	ns
		4+	3+	3	3	4.717 ± 0.714 (24)	5.433 ± 0.587 (24)	-5.385	<0.01
		3+	2+	2	2	3.098 ± 0.549 (43)	4.500 ± 0.283 (2)	-3.561	<0.01

Table 21. Mean lengths of otoliths collected in different regions.

Region	Mean length[a] at age ± s.d (n)							
	0+	1+	2+	3+	4+	5+	6+	7+
Chukchi	-	2.70 ± 0.82 (5)	3.53 ± 0.99 (36)	4.84 ± 1.34 (12)	6.78 ± 0.66 (21)	7.80 ± 0.54 (8)	-	-
Beaufort	2.08 ± 0.36 (16)	2.96 ± 0.68 (73)	4.04 ± 0.84 (172)	6.10 ± 0.77 (86)	7.04 ± 0.78 (39)	8.19 ± 0.86 (14)	9.30 ± 0.41 (4)	9.80 ± 1.41 (2)
Baffin	1.61 ± 0.31 (720)	2.29 ± 0.48 (588)	3.63 ± 0.84 (207)	5.34 ± 0.88 (141)	6.84 ± 0.88 (67)	7.98 ± 1.03 (19)	8.30 ± 0.00 (2)	-
Grise	2.11 ± 0.37 (8)	3.12 ± 0.78 (142)	4.47 ± 0.93 (336)	5.94 ± 0.87 (358)	7.27 ± 0.83 (231)	8.54 ± 0.73 (177)	9.30 ± 0.89 (23)	-
Pond--village, Kounuk	1.67 ± 0.42 (43)	2.88 ± 0.61 (917)	3.56 ± 0.75 (1021)	5.53 ± 0.93 (543)	6.59 ± 0.72 (298)	7.37 ± 1.02 (51)	9.16 ± 1.38 (7)	-
Pond--ice edge	1.52 ± 0.36 (45)	2.60 ± 0.65 (567)	3.82 ± 0.73 (1180)	5.10 ± 0.80 (583)	6.37 ± 0.86 (182)	7.09 ± 0.71 (29)	8.80 ± 0.00 (2)	-
Clyde	-	2.80 ± 0.50 (3)	4.02 ± 0.71 (18)	5.27 ± 0.72 (54)	6.90 ± 1.42 (20)	8.63 ± 0.29 (3)	-	-
Labrador	1.98 ± 0.33 (177)	2.43 ± 0.52 (153)	4.44 ± 0.78 (33)	5.26 ± 0.32 (13)	7.80 ± 0.00 (1)	9.80 ± 0.00 (1)	-	-

[a] Mean lengths ± s.d. are in mm.

Table 22. Lengths of Arctic cod otoliths from four regions in different years.

Region/test	Mean otolith length at age in mm ± s.d (n)							
	0+	1+	2+	3+	4+	5+	6+	7+
Grise Fiord 1978	-	3.5 ± 0.8 (38)	4.9 ± 0.7 (148)	5.9 ± 0.9 (184)	7.2 ± 0.9 (103)	8.6 ± 0.8 (86)	9.0 ± 0.9 (14)	-
1979	2.0 ± 0.6 (7)	3.0 ± 0.7 (74)	3.9 ± 1.0 (142)	5.9 ± 1.0 (87)	7.3 ± 0.8 (64)	8.5 ± 0.7 (76)	10.0 ± 0.8 (7)	-
F	-	1.31	2.04	1.23	1.27	1.31	1.27	-
t (d.f.)	-	3.26 (110)	9.83 (253)	0.00 (269)	-0.75 (165)	0.85 (160)	-2.48 (19)	-
P	-	<0.01	<0.01	>0.1	>0.1	>0.1	>0.02	-
Pond Inlet--ice edge 1978	1.6 ± 0.4 (25)	2.5 ± 0.6 (370)	3.5 ± 1.0 (321)	5.1 ± 0.9 (150)	6.1 ± 0.8 (53)	6.9 ± 1.0 (11)	-	-
1979	1.5 ± 0.3 (13)	3.2 ± 0.7 (138)	4.0 ± 0.6 (773)	5.1 ± 0.8 (429)	6.5 ± 0.9 (135)	7.2 ± 0.7 (20)	8.6 ± 0.0 (2)	-
F	1.78	1.36	2.78	1.27	1.27	2.04	-	-
t (d.f.)	0.79 (36)	-10.41 (217)	-8.36 (420)	0.00 (238)	-2.98 (186)	-0.98 (29)	-	-
P	>0.1	<0.01	<0.01	>0.1	<0.01	>0.1	-	-
Baffin 1976	1.7 ± 0.2 (608)	2.2 ± 0.4 (402)	4.0 ± 0.8 (41)	5.3 ± 0.8 (67)	6.5 ± 0.5 (30)	7.5 ± 0.9 (9)	-	-
1978	1.7 ± 0.4 (33)	2.6 ± 0.4 (162)	3.4 ± 0.8 (117)	5.5 ± 0.9 (48)	7.2 ± 1.0 (34)	8.4 ± 0.9 (10)	-	-
1979	1.2 ± 1.2 (2)	2.8 ± 0.9 (6)	4.2 ± 0.5 (31)	5.5 ± 0.8 (18)	6.9 ± 0.3 (3)	-	8.4 ± 0.2 (2)	-
ANOVA F	-	51.68	20.19	0.81	5.13	-	-	-
t (d.f.)	0.00 (33)	-	-	-	-	-2.17 (17)	-	-
P	>0.1	>0.01	>0.01	>0.05	>0.05	>0.02	-	-
Beaufort 1977	2.1 ± 0.3 (13)	2.8 ± 0.5 (51)	3.7 ± 0.6 (74)	5.8 ± 0.8 (28)	6.8 ± 0.7 (15)	8.0 ± 0.6 (9)	9.2 (1)	10.8 (1)
1978	-	3.6 ± 0.7 (12)	3.9 ± 0.7 (54)	6.4 ± 0.6 (46)	7.3 ± 0.7 (22)	8.4 ± 1.2 (5)	9.3 ± 0.5 (3)	8.7 (1)
1979	2.3 ± 0.6 (3)	3.1 ± 0.9 (10)	4.8 ± 0.9 (44)	5.6 ± 0.8 (12)	6.5 ± 1.0 (2)	-	-	-
ANOVA F	-	7.20	33.38	11.13	-	-	-	-
t (d.f.)	-0.87 (14)	-	-	-	-2.13 (35)	-0.85 (12)	-	-
P	>0.1	>0.05	>0.25	>0.05	>0.02	>0.1	-	-

Table 23. Otolith length-fork length relationships for Arctic cod in the North American Arctic. All regressions were calculated using the conventional least squares approach.

Area	Month(s)	Year(s)	Fork length (FL)--otolith length (OL) equation[a]	Range in fork lengths (mm)	r	n	Source
N Bering Sea	Mar-Oct	1976-77	FL = 21.98 (OL) +15.88	70-210	0.98	202	Frost and Lowry 1980, 1981
Chukchi Sea-Pt. Lay	Jul-Aug	1983	FL = 22.05 (OL) +9.87	52-222	0.98	82	this study
Beaufort Sea-Simpson Lagoon	Jul-Sep	1977	FL = 20.92 (OL) +17.69	54-251	0.97	189	this study
	Jul-Nov	1978	FL = 22.86 (OL) +11.04	64-235	0.96	142	this study
	Feb-Nov	1979	FL = 21.36 (OL) +14.12	54-153	0.98	61	this study
Cornwallis Island	Jul-Sep	1976	FL = 20.86 (OL) +19.33	24-178	0.99	181	Bain and Sekerak 1978
	Aug-Sep	1976	FL = 22.17 (OL) +16.45	122-239	0.89	200	this study
	Aug-Sep	1977	FL = 22.27 (OL) +19.96	110-252	0.86	89	this study
Pond Inlet-Button Point	Jul	1978	FL = 20.61 (OL) +14.90	65-142	0.98	34	this study
Tremblay Sound	Aug	1978	FL = 10.63 (OL) +49.35	71-100	0.66	91	this study
Button Point	May-Jul	1979	FL = 21.48 (OL) +19.20	52-222	0.97	55	this study
offshore ice edge	Jun	1979	FL = 21.34 (OL) +11.62	53-192	0.90	107	this study
Labrador	Sep	1978	FL = 24.70 (OL) +8.91	46-258	0.99	42	Lilly 1978

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[a] FL and OL values are in mm.

Table 24. Numbers of otoliths used in comparisons of otolith lengths at various annular marks.

Year of hatching	Age class	Location[a]/year of capture/age of capture/ (number of otoliths measured)	Number of areas compared
1973	5+	GR/78/5/(20); PO/78/5/(20)	2
	4+, 3+, 2+, 1+, 0+	the above plus BE/77/4/(10); BA/77/4/(70)	4
1974	5+	GR/79/5/(20); PO/79/5/(20)	2
	4+	the above plus GR/78/4/(20); PO/78/4/(20); BE/78/4/(17); BA/78/4/(20)	4
	3+, 2+, 1+, 0+	the above plus BE/77/3/(15); BA/77/3/(75)	4
1975	4+	GR/79/4/(20); PO/79/4/(20); CL/79/4/(20)	3
	3+	the above plus GR/78/3/(20); PO/78/3/(20); BE/78/3/(20); BA/78/3/(20)	5
	2+, 1+, 0+	the above plus BE/77/2/(20); BA/77/2/(28)	5
1976	3+	GR/79/3/(20); PO/79/3/(53); CL/79/3/(20); BA/79/3/(6)	4
	2+, 1+, 0+	the above plus GR/78/2/(20); PO/78/2/(37); BE/78/2/(20); BA/78/2/(20)	5
1977	2+	GR/79/2/(20); PO/79/2/(66); BE/79/2/(20); BA/79/2/(16); LA/79/2/(20)	5
	1+, 0+	the above plus GR/78/1/(20); PO/78/1/(33); BA/78/1/(20)	5
1978	1+	GR/79/1/(20); PO/79/1/(33); LA/79/1/(20)	3
	0+	PO/78/0/(20); BA/78/0/(20)	2
1979	0+	PO/79/0/(20); LA/79/0/(20)	2

[a] Location codes are as follows: BA = Baffin, GR = Grise Fiord, PO = Pond Inlet (ice edge, village and Kounuk samples combined), CL = Clyde River, LA = Labrador, BE = Beaufort Sea (Simpson Lagoon).

Table 25. Statistical comparisons of measurements (in mm) of Arctic cod otoliths from fish hatched in 1973 and captured in any year (1977-78).

Otolith measurement	Region	Mean length ± s.d. (n)	Kruskal-Wallis H(P)	Dunn's interpretations[a] (P<0.01)
R_4	Baffin	6.5 ± 1.0 (69)		
	Beaufort	6.6 ± 0.7 (10)	10.04 (<0.02)	
	Pond	6.6 ± 0.8 (20)		
	Grise	7.1 ± 0.6 (20)		
R_3	Baffin	5.3 ± 0.9 (70)		
	Beaufort	5.5 ± 0.7 (10)	9.59 (<0.05)	
	Pond	5.2 ± 0.9 (20)		
	Grise	5.8 ± 0.6 (20)		
R_2	Baffin	3.8 ± 0.7 (70)		
	Beaufort	3.9 ± 0.6 (10)	12.43 (<0.01)	PO<GR
	Pond	3.6 ± 0.5 (20)		
	Grise	4.2 ± 0.5 (20)		
R_1	Baffin	1.5 ± 0.4 (70)		
	Beaufort	1.8 ± 0.6 (10)	10.03 (<0.02)	
	Pond	1.8 ± 0.4 (20)		
	Grise	1.6 ± 0.3 (20)		
R_4-R_3	Baffin	1.2 ± 0.3 (69)		
	Beaufort	1.2 ± 0.5 (10)	4.72 (>0.1)	
	Pond	1.4 ± 0.3 (20)		
	Grise	1.3 ± 0.2 (20)		
R_3-R_2	Baffin	1.5 ± 0.4 (69)		
	Beaufort	1.6 ± 0.6 (10)	2.35 (>0.1)	
	Pond	1.6 ± 0.6 (20)		
	Grise	1.6 ± 0.3 (20)		
R_2-R_1	Baffin	2.3 ± 0.6 (69)		
	Beaufort	2.1 ± 0.5 (10)	21.74 (<0.01)	PO<GR
	Pond	1.8 ± 0.6 (20)		
	Grise	2.7 ± 0.4 (20)		
R_1-R_0	Baffin	1.2 ± 0.4 (69)		
	Beaufort	1.5 ± 0.6 (10)	10.45 (<0.02)	
	Pond	1.5 ± 0.4 (20)		
	Grise	1.3 ± 0.3 (20)		

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[a] Regional names are abbreviated as follows:
PO = Pond; GR = Grise; CL = Clyde; BA = Baffin; BE = Beaufort; LA = Labrador.

Table 26. Statistical comparisons of measurements of Arctic cod otoliths from fish hatched in 1974 and captured in any year (1977-79).

Otolith measurement	Region	Mean length ± s.d. (n)	Kruskal-Wallis H(P)	Dunn's interpretations[a] (P<0.01)
R_4	Baffin	6.6 ± 0.9 (20)		
	Beaufort	7.1 ± 0.7 (17)		PO<GR
	Pond	6.3 ± 1.0 (40)	18.77 (<0.001)	
	Grise	7.1 ± 0.6 (40)		
R_3	Baffin	5.2 ± 0.8 (95)		BA<BE,GR
	Beaufort	5.9 ± 0.9 (32)	25.68 (<0.001)	PO<BE
	Pond	5.1 ± 0.9 (40)		PO<GR
	Grise	5.8 ± 0.6 (40)		
R_2	Baffin	3.7 ± 0.8 (95)		
	Beaufort	4.3 ± 0.8 (32)	14.76 (<0.01)	BA<BE
	Pond	3.8 ± 0.8 (40)		
	Grise	4.1 ± 0.4 (40)		
R_1	Baffin	1.6 ± 0.4 (95)		BA<BE,PO
	Beaufort	2.1 ± 0.6 (32)	28.94 (<0.001)	GR<BE
	Pond	1.9 ± 0.5 (40)		
	Grise	1.6 ± 0.3 (40)		
R_4-R_3	Baffin	1.2 ± 0.4 (20)		
	Beaufort	1.1 ± 0.4 (17)	8.55 (>0.02)	
	Pond	1.2 ± 0.3 (40)		
	Grise	1.3 ± 0.2 (40)		
R_3-R_2	Baffin	1.5 ± 0.4 (95)		PO<GR
	Beaufort	1.5 ± 0.6 (32)	15.32 (<0.01)	
	Pond	1.3 ± 0.4 (40)		
	Grise	1.7 ± 0.4 (40)		
R_2-R_1	Baffin	2.2 ± 0.7 (95)		PO<GR
	Beaufort	2.2 ± 0.6 (32)	17.41 (<0.001)	
	Pond	1.9 ± 0.6 (40)		
	Grise	2.5 ± 0.4 (40)		
R_1-R_0	Baffin	1.3 ± 0.4 (95)		BA<BE,PO
	Beaufort	1.8 ± 0.6 (32)	28.73 (<0.001)	GR<BE
	Pond	1.6 ± 0.5 (40)		
	Grise	1.3 ± 0.3 (40)		

[a] Regional names are abbreviated as follows:
PO = Pond; GR = Grise; CL = Clyde; BA = Baffin; BE = Beaufort; LA = Labrador.

Table 27. Statistical comparisons of measurements of Arctic cod otoliths from fish hatched in 1975 and captured in any year (1977-79).

Otolith measurement	Region	Mean length ± s.d. (n)	Kruskal-Wallis H(P)	Dunn's interpretations[a] (P<0.01)
R_3	Baffin	4.9 ± 0.7 (20)	32.62 (<0.001)	BA<BE,GR PO<BE CL<GR
	Beaufort	6.1 ± 0.7 (20)		
	Pond	5.1 ± 0.8 (40)		
	Grise	5.7 ± 0.7 (40)		
	Clyde	5.4 ± 0.7 (20)		
R_2	Baffin	3.9 ± 0.6 (48)	4.92 (>0.1)	
	Beaufort	4.0 ± 0.9 (40)		
	Pond	3.8 ± 0.7 (40)		
	Grise	4.1 ± 0.5 (40)		
	Clyde	3.9 ± 0.6 (20)		
R_1	Baffin	1.5 ± 0.4 (48)	42.63 (<0.001)	BA,PO,GR,CL<BE
	Beaufort	2.1 ± 0.5 (40)		
	Pond	1.6 ± 0.4 (40)		
	Grise	1.7 ± 0.4 (40)		
	Clyde	1.7 ± 0.4 (20)		
R_3-R_2	Baffin	1.1 ± 0.4 (20)	21.96 (<0.001)	BA<GR
	Beaufort	1.5 ± 0.8 (20)		
	Pond	1.4 ± 0.4 (40)		
	Grise	1.6 ± 0.4 (40)		
	Clyde	1.4 ± 0.5 (20)		
R_2-R_1	Baffin	2.4 ± 0.5 (48)	24.54 (<0.001)	BE<BA,GR
	Beaufort	1.8 ± 0.7 (40)		
	Pond	2.2 ± 0.6 (40)		
	Grise	2.4 ± 0.4 (40)		
	Clyde	2.3 ± 0.6 (20)		
R_1-R_0	Baffin	1.2 ± 0.4 (48)	42.21 (<0.001)	BA,PO,GR,CL<BE
	Beaufort	1.8 ± 0.5 (40)		
	Pond	1.3 ± 0.4 (40)		
	Grise	1.4 ± 0.4 (40)		
	Clyde	1.2 ± 0.9 (20)		

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[a] Regional names are abbreviated as follows:
PO = Pond; GR = Grise; CL = Clyde; BA = Baffin; BE = Beaufort; LA = Labrador.

Table 28. Statistical comparisons of measurements of Arctic cod otoliths from fish hatched in 1976 and captured in any year (1978-79).

Otolith measurement	Region	Mean length ± s.d. (n)	Kruskal-Wallis H(P)	Dunn's interpretations[a] (P<0.01)
R_2	Baffin	3.9 ± 0.4 (26)		
	Beaufort	3.8 ± 0.8 (20)		PO<BA,GR,CL
	Pond	3.3 ± 0.6 (75)	59.03 (<0.001)	
	Grise	4.0 ± 0.4 (40)		
	Clyde	3.9 ± 0.3 (20)		
R_1	Baffin	1.5 ± 0.4 (26)		
	Beaufort	2.5 ± 0.4 (20)		BA,PO,GR,CL<BE
	Pond	1.7 ± 0.4 (75)	57.18 (<0.001)	
	Grise	1.4 ± 0.3 (40)		
	Clyde	1.4 ± 0.3 (20)		
R_2-R_1	Baffin	2.4 ± 0.4 (26)		
	Beaufort	1.4 ± 0.8 (20)		BE,PO<BA,GR,CL
	Pond	1.6 ± 0.6 (75)	87.21 (<0.001)	
	Grise	2.6 ± 0.4 (40)		
	Clyde	2.5 ± 0.5 (20)		
R_1-R_0	Baffin	1.2 ± 0.4 (26)		
	Beaufort	2.2 ± 0.4 (20)		BA,PO,GR,CL<BE
	Pond	1.4 ± 0.4 (75)	57.71 (<0.001)	
	Grise	1.1 ± 0.3 (40)		
	Clyde	1.1 ± 0.2 (20)		

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[a] Regional names are abbreviated as follows:
PO = Pond; GR = Grise; CL = Clyde; BA = Baffin; BE = Beaufort; LA = Labrador.

Table 29. Statistical comparisons of measurements of Arctic cod otoliths from fish hatched in 1977 and captured in any year (1978-79).

Otolith measurement	Region	Mean length ± s.d. (n)	Kruskal-Wallis H(P)	Dunn's interpretations[a] (P<0.01)
R_1	Baffin	1.4 ± 0.3 (36)		
	Beaufort	2.5 ± 0.6 (20)		
	Pond	1.4 ± 0.3 (70)	75.69 (<0.001)	PO,GR,BA<LA,BE
	Grise	1.5 ± 0.3 (40)		
	Labrador	2.1 ± 0.4 (20)		
R_1-R_0	Baffin	1.1 ± 0.3 (36)		
	Beaufort	2.2 ± 0.6 (20)		
	Pond	1.2 ± 0.3 (70)	73.89 (<0.001)	PO,GR,BA<LA,BE
	Grise	1.2 ± 0.3 (40)		
	Labrador	1.8 ± 0.4 (20)		

[a] Regional names are abbreviated as follows:
PO = Pond; GR = Grise; CL = Clyde; BA = Baffin; BE = Beaufort; LA = Labrador.

Table 30. Statistical comparisons of measurements of Arctic cod otoliths from fish hatched in 1978 and collected in any year (1978-79).

Otolith measurement	Region	Mean length ± s.d. (n)	Kruskal-Wallis H(P)	Dunn's interpretations[a] (P<0.01)
R_1	Pond	1.4 ± 0.3 (33)		
	Grise	1.3 ± 0.2 (20)	38.05 (<0.01)	PO<LA
	Labrador	2.2 ± 0.3 (20)		GR<LA
R_1-R_0	Pond	1.1 ± 0.3 (33)		
	Grise	1.0 ± 0.2 (20)	38.75 (<0.01)	PO<LA
	Labrador	1.9 ± 0.3 (20)		GR<LA

[a] Regional names are abbreviated as follows:
PO = Pond; GR = Grise; CL = Clyde; BA = Baffin; BE = Beaufort; LA = Labrador.

Table 31. Statistical comparisons of measurements of Arctic cod otoliths from fish hatched in 1979 and collected in that year.

Year collected	Region (n)/test	Mean otolith measurement ± s.d. Total length
1979	Pond (20)	1.4 ± 0.2
	Labrador (20)	2.1 ± 0.4
	Mann-Whitney P	<0.01

Table 32. Annual growth increments (mm) in Arctic cod otoliths.

Differences in ring measurements	Year of hatching	Mean difference in ring measurements ± s.d. (n) by region				
		Baffin	Grise	Pond	Beaufort	All regions
R_1-R_0	1973	1.17 ± 0.4 (69)	1.25 ± 0.3 (20)	1.47 ± 0.4 (20)	1.50 ± 0.6 (10)	1.29 ± 0.4 (119)
	1974	1.25 ± 0.4 (95)	1.31 ± 0.3 (40)	1.57 ± 0.5 (40)	1.77 ± 0.6 (32)	1.44 ± 0.4 (207)
	1975	1.22 ± 0.4 (48)	1.35 ± 0.4 (40)	1.28 ± 0.4 (40)	1.85 ± 0.5 (40)	1.41 ± 0.4 (168)
	1976	1.17 ± 0.4 (26)	1.13 ± 0.3 (40)	1.38 ± 0.4 (75)	2.16 ± 0.4 (20)	1.39 ± 0.4 (161)
R_2-R_1	1973	2.30 ± 0.6 (69)	2.70 ± 0.4 (20)	1.83 ± 0.6 (20)	2.06 ± 0.5 (10)	2.27 ± 0.6 (119)
	1974	2.17 ± 0.7 (95)	2.51 ± 0.4 (40)	1.94 ± 0.6 (40)	2.23 ± 0.6 (32)	2.20 ± 0.6 (207)
	1975	2.42 ± 0.5 (48)	2.42 ± 0.4 (40)	2.20 ± 0.6 (40)	1.81 ± 0.7 (40)	2.21 ± 0.6 (168)
	1976	2.40 ± 0.4 (26)	2.60 ± 0.4 (40)	1.62 ± 0.6 (75)	1.36 ± 0.8 (20)	1.95 ± 0.6 (161)
R_3-R_2	1973	1.47 ± 0.4 (69)	1.59 ± 0.3 (20)	1.61 ± 0.6 (20)	1.61 ± 0.6 (10)	1.54 ± 0.4 (119)
	1974	1.50 ± 0.4 (95)	1.69 ± 0.4 (40)	1.34 ± 0.4 (40)	1.55 ± 0.6 (32)	1.51 ± 0.4 (207)
	1975	1.08 ± 0.4 (20)	1.65 ± 0.4 (40)	1.36 ± 0.4 (40)	1.51 ± 0.8 (20)	1.43 ± 0.5 (120)

Table 33. Comparisons of rates of growth in otoliths and fork lengths of Arctic cod.

	Walford Equations: Length at age +1 =		
Area/Data Set	Otoliths (mm)	Fork lengths (mm)	Comparisons of slopes[a]
Chukchi/Point Lay	1.05 length at age +1.022	1.09 length at age +17.98	t = 0.516, df = 4, P>0.1
Beaufort Sea/Simpson Lagoon 1977, 1978, 1979	0.850 length at age +2.032	0.783 length at age +54.10	t = 1.498, df = 8, P>0.1
Cornwallis Island Aug-Sep 1976 Aug-Sep 1977	0.798 length at age +1.968	0.599 length at age +82.13	t = 3.744, df = 4, P<0.02
Pond Inlet/Ice edge 1978, 1979	1.028 length at age +1.510	1.313 length at age +3.63	t = 3.480, df = 4, P<0.05

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[a] Follows method of Johnson and Leone (1964: 393).

Table 34. Mean lengths of otoliths collected in different regions. Frequency distributions for these data are given in Fig. 27.

Region	Mean length[a] at age (n)						
	1+	2+	3+	4+	5+	6+	7+
Chukchi	2.70 (5)	3.53 (36)	4.84 (12)	6.78 (21)	7.80 (8)	-	-
Beaufort	2.96 (73)	4.04 (172)	6.10 (86)	7.04 (39)	8.19 (14)	9.30 (4)	9.80 (2)
Baffin	2.29 (588)	3.63 (207)	5.34 (141)	6.84 (67)	7.98 (19)	8.30 (2)	-
Grise	3.12 (142)	4.47 (336)	5.94 (358)	7.27 (231)	8.54 (177)	9.30 (23)	-
Pond--village, Kounuk	2.88 (917)	3.56 (1021)	5.53 (543)	6.59 (298)	7.37 (51)	9.16 (7)	-
Pond--ice edge	2.60 (567)	3.82 (1180)	5.10 (583)	6.37 (182)	7.09 (29)	8.80 (2)	-
Clyde	2.80 (3)	4.02 (18)	5.27 (54)	6.90 (20)	8.63 (3)	-	-
Labrador	2.43 (153)	4.44 (33)	5.26 (13)	7.80 (1)	9.80 (1)	-	-

[a] Mean lengths are in mm.

Table 35. Ford's growth coefficients calculated from otolith measurements for various age groups of Arctic cod in five regions.

Region		Ford's growth coefficients		
		all ages[a]	ages 1+ to 3+	ages 3+ to 5+
Beaufort		0.905	1.90	1.22 (0.657)[b]
Baffin		0.943	1.27	0.759
Grise Fiord		0.900	1.08	0.782
Pond--village, Kounuk		0.902	2.89	0.735
Pond--ice edge		0.879	1.04	0.567
Test for homogeneity	F	0.06	5.11	2.00
	df	4,11	4,1	4,1
	P	>0.05	>0.05	>0.05

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[a] These values are the slopes of equations plotted in Figure 30.
[b] Value in parentheses is recalculated from data for ages 2+-5+.

Table 36. Mean fork lengths and Ford's growth coefficients calculated for Arctic cod in seven areas.

Area (Year)	Mean fork length in mm at age (n)						Source	Ford's growth coefficient
	1+	2+	3+	4+	5+	6+		
N Bering Sea (1978)	101 (-)	134 (-)	155 (-)	174 (-)	191 (-)	209 (-)	Lowry and Frost 1981	0.834
Chukchi/Beaufort (1977)	73 (1)	118 (-)	144 (-)	175 (-)	-	-	Lowry and Frost 1981	0.778
Chukchi/Point Lay (1983)	70 (5)	84 (36)	116 (12)	158 (21)	184 (8)	-	this study	1.098
Beaufort/Simpson Lagoon (1977-80)	84 (225)	128 (137)	159 (94)	180 (19)	209 (9)	240 (4)	Craig et al. 1982	0.694
Cornwallis Island (1976-77)	62 (8)	136 (64)	164 (660)	184 (251)	216 (25)	206 (1)	Bain and Sekerak 1978, this study	0.990
Pond Inlet/Ice edge (1978-79)	62 (31)	102 (94)	125 (40)	136 (3)	-	-	Bradstreet 1982	0.544
Labrador Sea (1978)	103 (31)	158 (28)	207 (19)	224 (14)	253 (96)	250 (1)	Wells 1980	0.715

Table 37. Mean lengths of otoliths from fish hatched in 1976-78 and captured in 1978-79 at Grise Fiord.

	Mean ± s.d. (n)			
Age	1+		2+	
Year collected	1978	1979	1978	1979
Year hatched	1977	1978	1976	1977
Measurement (mm)/test				
Total length	3.7 ± 0.4 (20)	2.5 ± 0.4 (20)	4.7 ± 0.5 (20)	4.0 ± 0.8 (20)
Mann-Whitney z(P)	5.40 (<0.01)		3.00 (<0.01)	
Length at R_2	-		3.9 ± 0.3 (20)	3.4 ± 0.6 (20)
Mann-Whitney z(P)	-		2.84 (<0.01)	
Length at R_1	1.5 ± 0.3 (20)	1.3 ± 0.2 (20)	1.4 ± 0.3 (20)	1.4 ± 0.4 (20)
Mann-Whitney z(P)	2.61 (0.01)		0.34 (>0.1)	
Second growth increment (R_2-R_1)	-		2.5 ± 0.5 (20)	2.0 ± 0.6 (20)
Mann-Whitney z(P)	-		2.78 (0.01)	
First growth increment (R_1-R_0)	1.2 ± 0.3 (20)	1.0 ± 0.2 (20)	1.1 ± 0.3 (20)	1.1 ± 0.4 (20)
Mann-Whitney z(P)	2.58 (0.01)		0.30 (>0.1)	

Table 58. Mortality rates of Arctic cod as determined from otoliths in various predators and locations.

Location	Predator	Number of otoliths	Number of samples	Mortality rate[a]					
				1+/0+	2+/1+	3+/2+	4+/3+	5+/4+	6+/5+
Grise Fiord	Ringed seal	646	36	-	-	.200	.213	-	-
	Bearded seal	125	5	-	-	-	.339	.846	.833
	Harp seal	379	16	-	-	-	.487	.259	.860
	White whale	125	5	-	-	-	.488	.435	.923
	Mean mortality rate (± s.d.)	1275	62	-	-	0.200 (0.00)	0.382 (0.13)	0.513 (0.30)	0.872 (0.05)
Baffin	Northern fulmar	68	24	-	-	-	.094	.316	-
	Thick-billed murre	1555	222	.117	.682	.378	.571	.875	.667
	Mean mortality rate (± s.d.)	1623	246	0.117 (0.00)	0.682 (0.00)	0.378 (0.00)	0.333 (0.34)	0.596 (0.40)	0.667 (0.00)
Pond Inlet-ice edge	Ringed seal	1280	58	-	-	.491	.692	.845	.882
	Narwhal	501	23	-	-	.206	.622	.877	-
	Thick-billed murre	807	74	-	.265	.739	.800	.667	-
	Mean mortality rate (± s.d.)	2588	155	-	0.265 (0.00)	0.479 (0.27)	0.705 (0.09)	0.796 (0.11)	0.882 (0.00)
Pond Inlet-village, Kounuk	Ringed seal	2358	115	-	-	.565	.518	.884	.955
	Bearded seal	147	6	-	-	.365	.360	.479	.667
	Harp seal	269	13	-	-	-	.059	.793	.882
	Narwhal	106	4	-	.279	.096	.893	-	-
	Mean mortality rate (± s.d.)	2880	138	-	0.279 (0.00)	0.342 (0.24)	0.458 (0.35)	0.718 (0.21)	0.835 (0.15)
Clyde	Bearded seal	98	7	-	-	-	.629	.850	-
Mean mortality rate (± s.d.) (all predators, all areas)		8464	608	0.117 (0.00)	0.409 (0.24)	0.380 (0.21)	0.483 (0.25)	0.677 (0.24)	0.847 (0.11)
	number of estimates			1	3	8	14	12	8

[a] Mortality rate A = 1-S, where S (survival rate) = e^{-Z} and Z (instantaneous mortality) = (log n_t - log n_{t-1}) 2.3026 where n = number of fish of age t or age t-1.

Table 39. Comparisons of regional mortality rates of Arctic cod.

	3+/2+		4+/3+		5+/4+		6+/5+	
Regions compared	t	P	t	P	t	P	t	P
GR vs. BA	-		0.241	>0.1	-0.270	>0.1	-	
GR vs. PI	-		-3.656	<0.02	1.534	>0.1	-	
GR vs. PVK	-		-0.407	>0.1	-0.970	>0.1	0.405	>0.1
BA vs. PI	-		-1.944	>0.1	-0.884	>0.1	-	
BA vs. PVK	-		-0.415	>0.1	-0.465	>0.1	-	
PI vs. PVK	0.657	>0.1	1.167	>0.1	0.570	>0.1	-	

GR = Grise Fiord, BA = Baffin, PI = Pond Inlet--ice edge, PVK = Pond Inlet--village and Kounuk.

Table 40. Summary of the major prey of ringed seals by region. Modified from Lowry et al. 1980^{a}.

Region	Winter	Spring	Summer	Autumn	Source
Kara Sea, Novaya Zemlya	Arctic cod	Hyperiid and gammarid amphipods, mysids		Arctic cod	Chapskii 1940
Sea of Okhotsk	Saffron cod, smelt, herring, and other fishes	Primarily euphausiids, also gammarid and hyperiid amphipods and shrimps		Saffron cod, smelt, herring, and other fishes	Fedoseev 1965
Bering and Chukchi Seas	Saffron cod				Lowry et al. 1980a
Beaufort Sea	Arctic cod	Gammarid amphipods, mysids, amphipods	Hyperiid amphipods, Arctic cod, euphausiids	Arctic cod, hyperiid amphipods	Lowry et al. 1980a
Barrow Strait	Hyperiid and gammarid amphipods	Hyperiid and gammarid amphipods, mysids		Arctic cod	Finley 1978 and unpublished data
Ellesmere Island	Arctic cod				Bradstreet and Finley 1983
Northern Baffin Island	Arctic cod				Bradstreet and Finley 1983
Southeast and east Baffin Island			Hyperiid amphipods and mysids		Dunbar 1941 Finley et al. 1983a
Labrador Coast	Gadid fish including Arctic cod	Gadid fish including Arctic cod	Mysids, euphausiids, amphipods		deGraaf et al. 1981
Southwest Baffin Island and Foxe Basin	Hyperiid amphipods offshore, mysids and Arctic cod nearshore--no seasonality was found				McLaren 1958
Ungava Bay	Mysids, euphausiids and various fishes--seasonality not indicated				McLaren 1958
Northwest Greenland	Arctic cod, amphipods and shrimps--seasonality not indicated				Vibe 1950

Table 41. Observations of feeding aggregations of marine mammals and seabirds in the eastern Canadian Arctic, 1976-1983.

Area[a]	Date	Mode of observation	Associated species: Marine mammals[b]	Associated species: Seabirds[c]	Habitat	Comments	Source
1A. Allen Bay	12 Aug 1976	shore-based	'many' RS	FUL, KIT IVG, GLG	coastal, beneath shore-fast ice	large numbers of Arctic cod washed up on shore, stomachs of seals taken in area were full of Arctic cod	Finley, Unpublished data
1B. Allen Bay	14 Sep 1976	shore-based	several hundred WW	FUL, KIT IVG, GLG	coastal, beneath shore-fast ice	large numbers of Arctic cod in tide pools and washed up on shore	Davis and Finley 1979
1C. Allen Bay	31 Jul 1977	shore-based	hundreds WW	not noted	coastal	stomach of white whale taken in area contained 10 kg of Arctic cod	Finley, Unpublished data
1D. Allen Bay	6 Sep 1977	shore-based	300 WW, 65 HS, 20 RS, 3 BS	FUL, KIT	coastal		Finley, Unpublished data
2. Franklin Strait	28 Aug 1976	aerial	hundreds HS, NAR, WW	FUL, KIT, IVG	mid channel, dense pack ice		Finley and Johnston 1977
3. Creswell Bay	28 Aug 1976	aerial, by boat	1500 WW, 50 NAR, 50 HS	FUL, KIT	coastal, no ice	thousands of cod washed on shore, stomachs of narwhals and ringed seals full of cod	Finley and Johnston 1977
4. Maxwell Bay	21 Sep 1976	aerial	550 WW, 85 NAR, 135 HS	FUL, KIT	head of fiord, new ice forming		Finley and Johnston 1977
5. Pond Inlet	6 Jul 1978	ice-based	100 NAR	FUL, GLG	300 m from fast-ice edge	narwhal stomach full of cod	Finley and Gibb 1982

Table 41. Concluded.

Area[a]	Date	Mode of observation	Associated species: Marine mammals[b]	Associated species: Seabirds[c]	Habitat	Comments	Source
6A. Eclipse Sound	16 Aug 1978	by boat	hundreds RS		fiord, scattered pack ice	seals filled with cod	Finley, Unpublished data
6B. Eclipse Sound	27 Aug 1978	shore-based, by boat	75 HS	FUL, KIT, JAEG	nearshore, no ice	huge shoals of small cod assembled in shallow water, seal full of same	Finley and Gibb, in press
7. Pond Inlet	3 Sep 1978	by boat	50 RS	KIT, FUL, THGL GLG	nearshore, scattered ice pans	seal full of large cod ($\bar{x}$ = 15.4 ± 0.9, n = 11)	Finley, Unpublished data
8. Bethune Inlet	15 Sep 1978	aerial	1800 WW, 145 HS	FUL, KIT	coastal, no ice	activity appeared dispersed over large area	Finley and Gibb, in press
9. Grise Fiord	15 Sep 1978	aerial	960 WW, 550 HS	IVG, FUL, KIT	coastal, no ice	near mouth of fiord	Koski and Davis 1979
9. Grise Fiord	23 Aug 1979	shore-based	200 HS	FUL, KIT, GLG	coastal, scattered pack ice	thousands of large debilitated cod washed up on shore after feeding activity	Finley and Gibb, in press
9. Grise Fiord	1 Sep 1979	shore-based, by boat	150 HS	FUL, KIT, GLG	coastal, scattered pack ice	large oil slick formed after feeding but no cod washed up on shore	Finley, Unpublished data
10. Resolute Bay	15 Aug 1979	local pers. comm.	hundreds WW	not noted	not noted	thousands cod washed up on shore	Sudluvinig, Resolute Bay, pers. comm.
11. Admiralty Inlet	30 Jun 1982	ice-based	100 WW, 100 NAR	KIT, JAEG	edge of fast ice	activity narrowly directed beneath the ice edge for >2 h; feeding birds disgorged Arctic cod	Finley et al. 1983b
12. Lancaster Sound	30 Jun- 1 Jul 1983	aerial	400 WW, 300 NAR, 50 HS	not noted	edge of fast ice	activity narrowly directed at one point beneath the ice edge. Aggregation lasted 2 days.	Finley et al. 1984

[a] Locations are referenced by number to Fig. 36.

[b] WW = white whale, NAR = narwhal, RS = ringed seal, HS = harp seal, BS = bearded seal.

[c] FUL = fulmar, KIT = kittiwake, IVG = ivory gull, GLG = glaucous gull, THGL = Thayer's gull, JAEG = jaeger.

Table 42. Lengths of Arctic cod otoliths (mm) taken by marine mammals in the Canadian Arctic.

Predator	Area[a]	Mean length	s.d.	Number otoliths	Number samples
Ringed seal	Pond Inlet	4.0	1.3	3638	173
	Grise Fiord	5.8	1.9	646	36
Bearded seal	Pond Inlet	5.1	2.2	147	6
	Grise Fiord	6.6	1.3	125	5
	Clyde River	6.2	1.5	125	5
Harp seal	Pond Inlet	5.4	1.5	269	13
	Grise Fiord	5.7	1.7	379	16
Narwhal	Pond Inlet	4.7	1.2	607	27
White whale	Grise Fiord	6.2	1.5	125	5

[a] Pond Inlet includes three areas combined: ice edge, village and Kounuk.

Table 43. Spearman rank correlations between numbers of otoliths in a seal stomach and the coefficient of variation of otolith length in that stomach.

		Range in:			
Species	Location/season	Numbers of otoliths in stomach	Coefficients of variation in otolith lengths[a]	Spearman rank coefficient between nos. of otoliths and coefficients of variation (n)	P
Ringed seal	Pond--village Open water 1978	26-292	9.9-45.8	-0.204 (56)	>0.1
	Pond--village Open water 1978	46-642	7.8-22.7	-0.073 (10)	>0.1
	Pond--village Open water 1978	37-1090	6.5-28.2	0.014 (35)	>0.1
Harp seal	Pond--village Open water 1978	61-349	9.2-23.6	-0.520 (10)	>0.1
	Pond--village Open water 1978	25-1092	7.5-40.1	-0.020 (10)	>0.1

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[a] Coefficients of variation were calculated from 25 otoliths randomly chosen from each stomach.

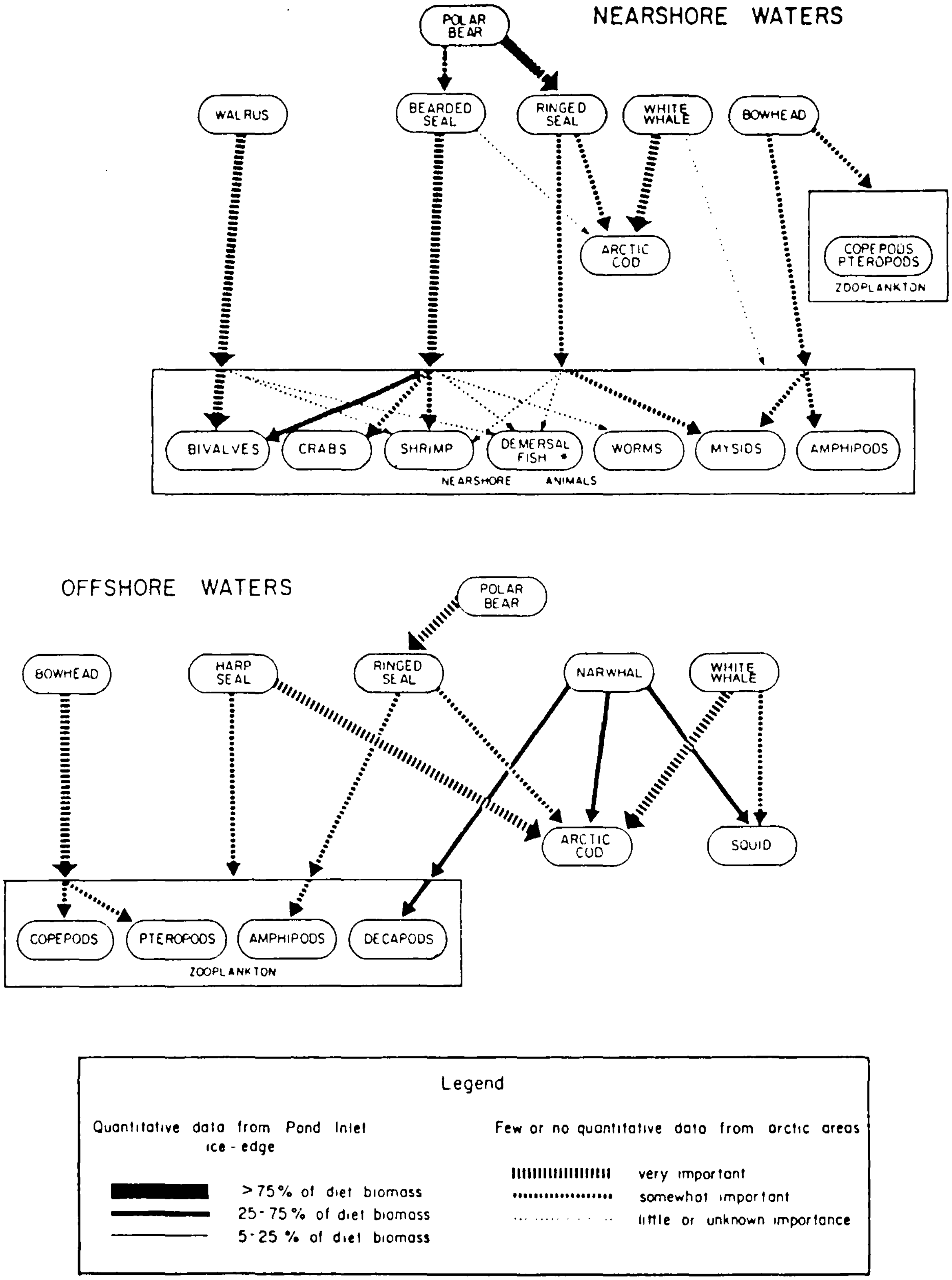


Fig. 1. Summary of major energy flows leading to marine mammals in the North American Arctic (from Davis et al. 1980).

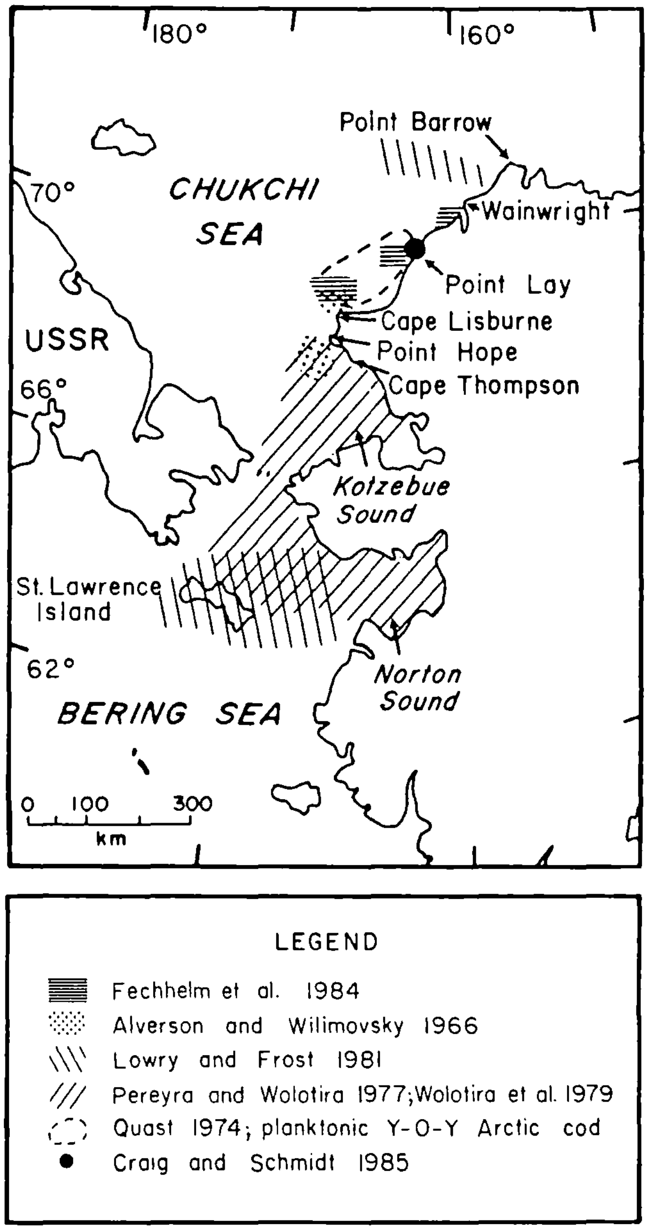


Fig. 2. Recorded distribution of Arctic cod in the eastern Bering and Chukchi seas.

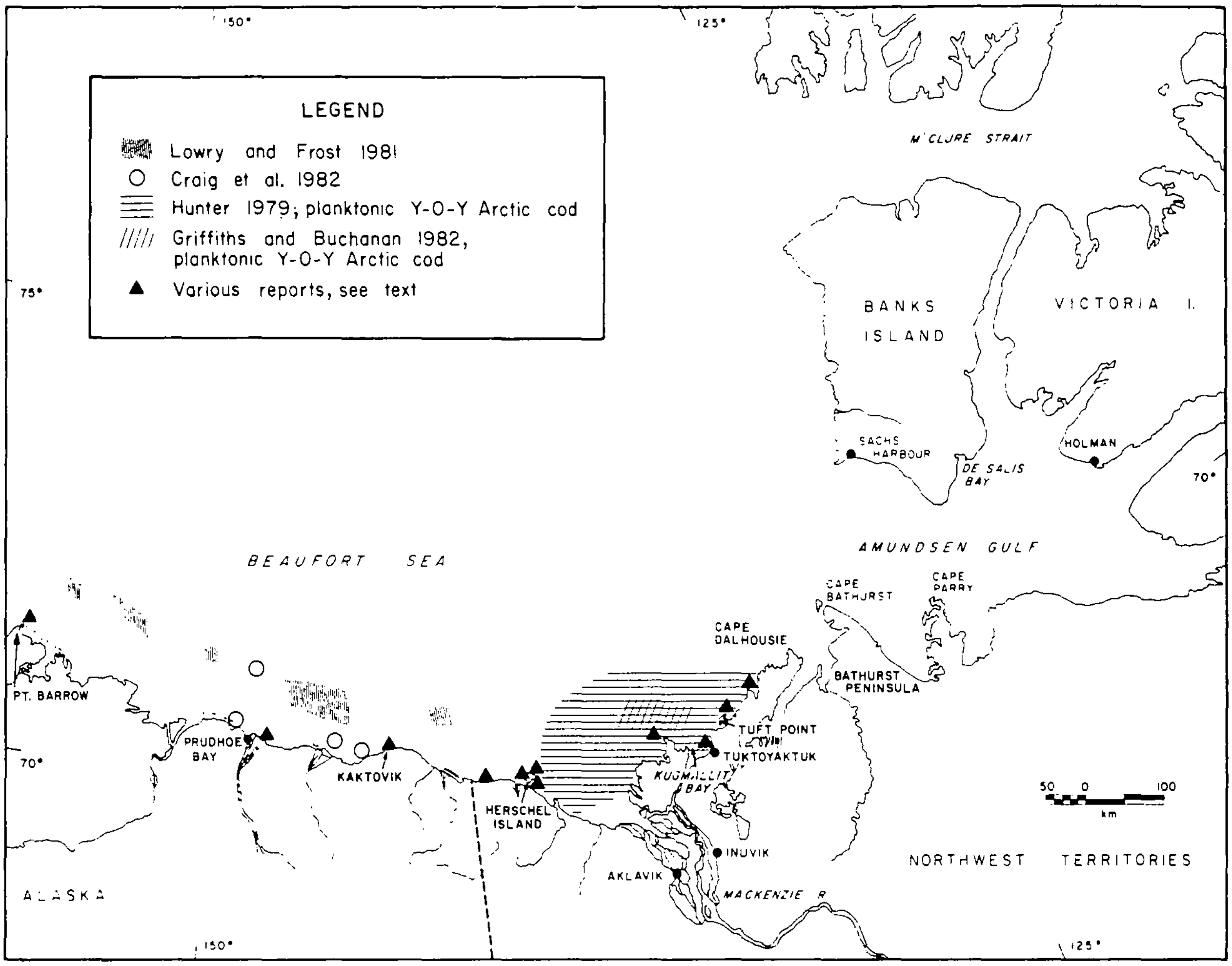


Fig. 3. Recorded distribution of Arctic cod in the Beaufort Sea.

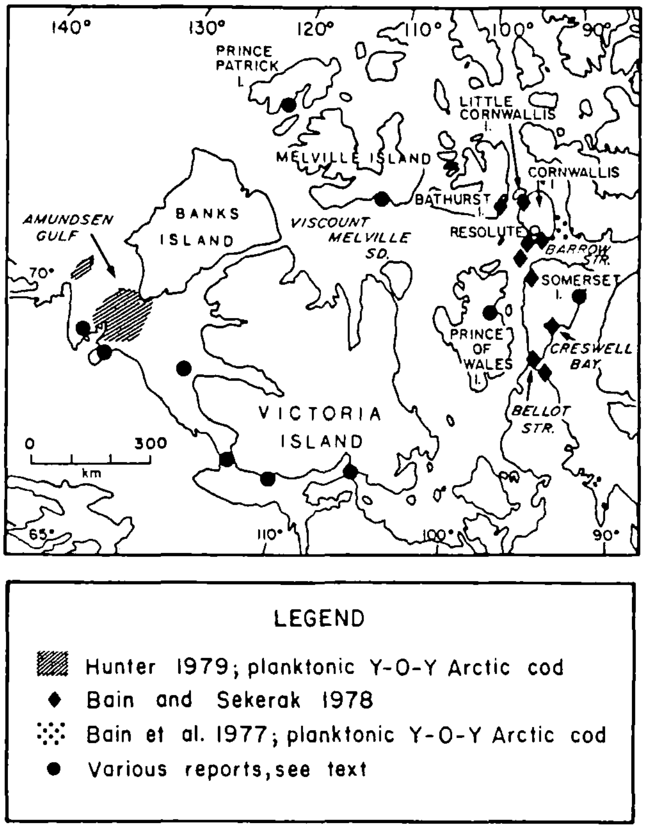


Fig. 4. Recorded distribution of Arctic cod in the western and central Arctic islands.

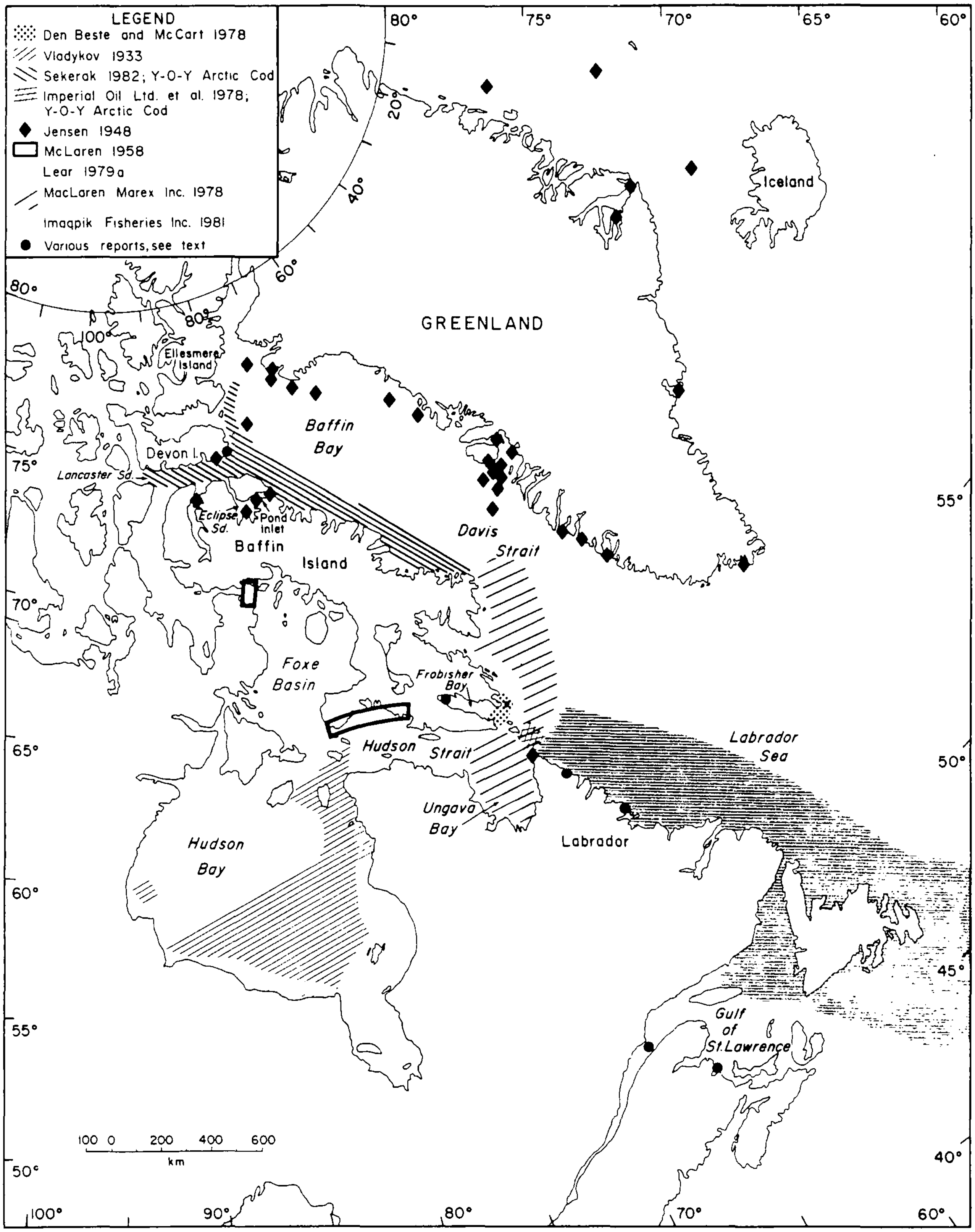


Fig. 5. Recorded distribution of Arctic cod in the eastern Arctic, Labrador Sea, and northwest Atlantic.

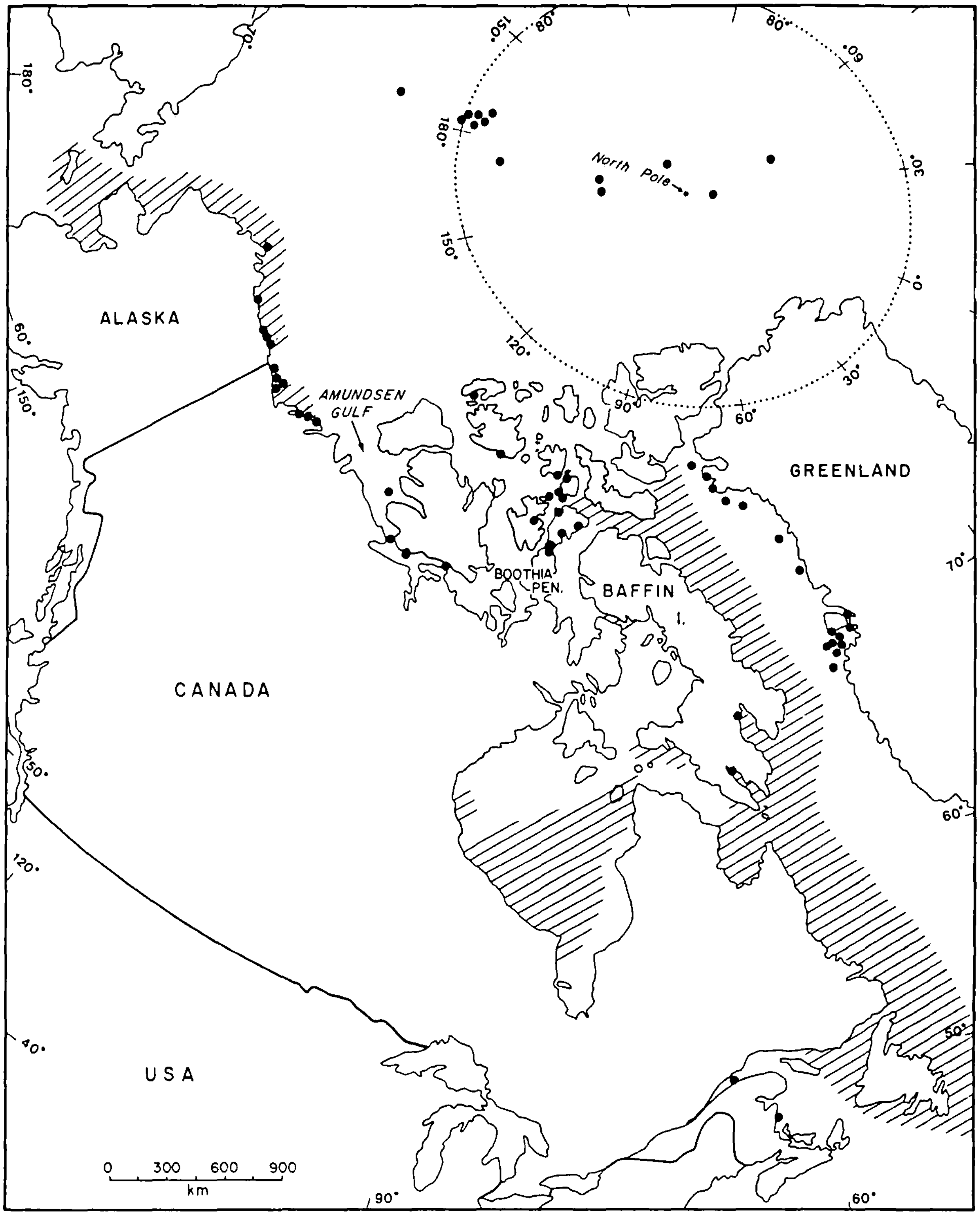


Fig. 6. Distribution of Arctic cod in the North American Arctic including recent records from near the North Pole. Shading represents regions where sampling has been sufficiently intense to establish that Arctic cod are generally found over the entire area.

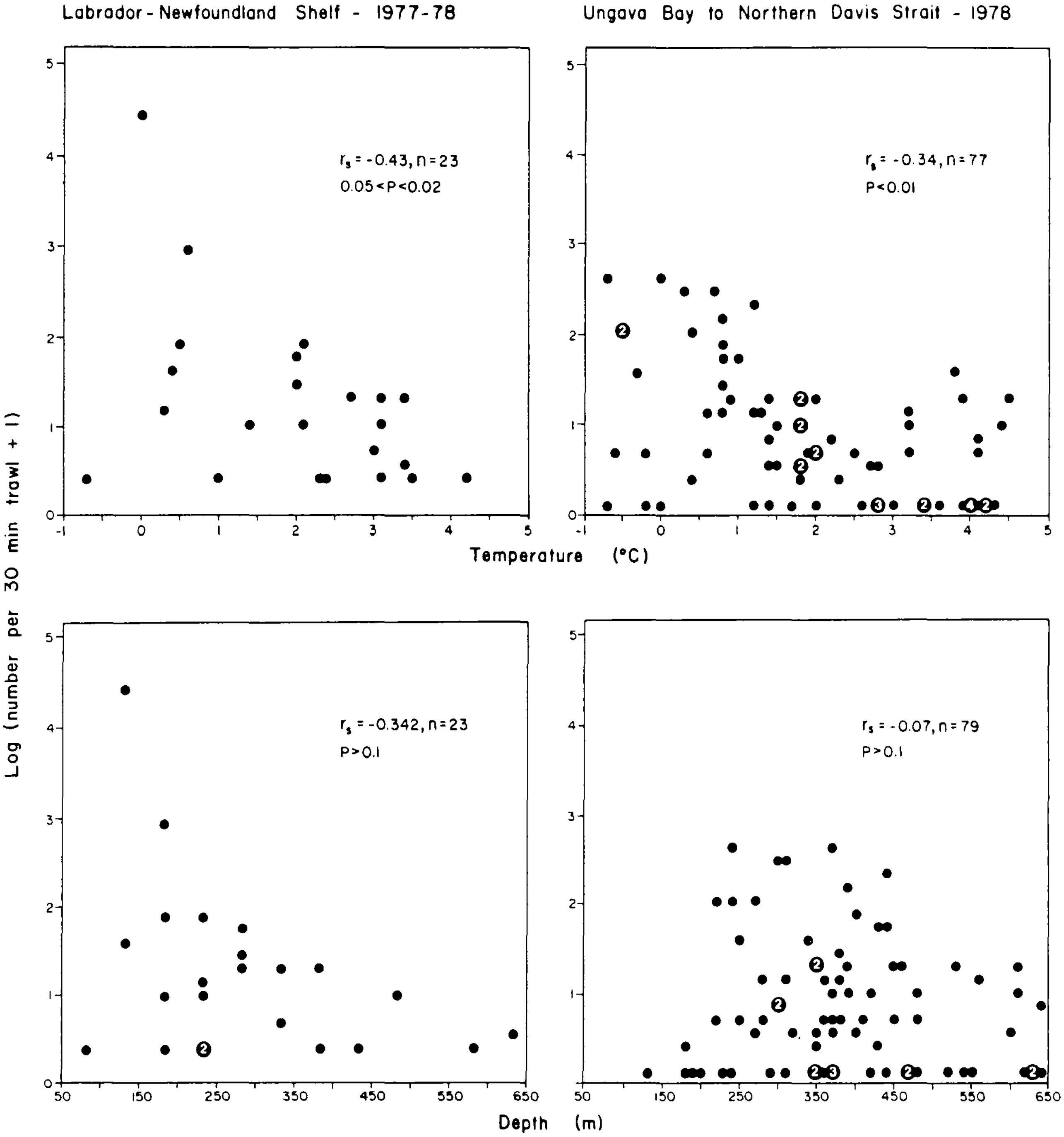


Fig. 7. Numbers of Arctic cod taken per 30-minute trawl versus temperature or depth in two areas. Data from the Labrador-Newfoundland shelf are from Lear (1979a) and those from Ungava Bay to northern Davis Strait are from McLaren Marex Inc. (1978).

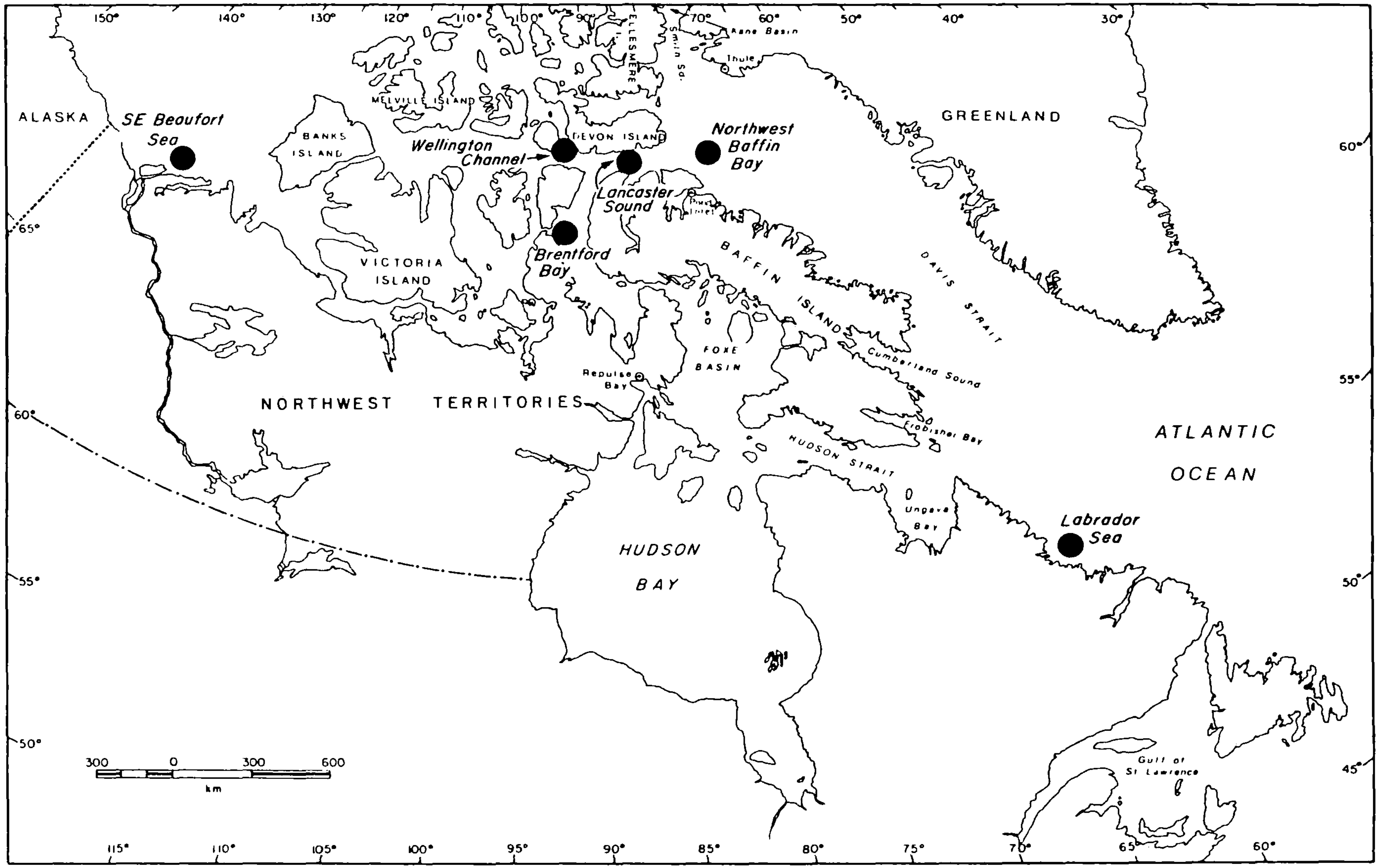


Fig. 8. Locations of Y-O-Y Arctic cod collections used for diet studies.

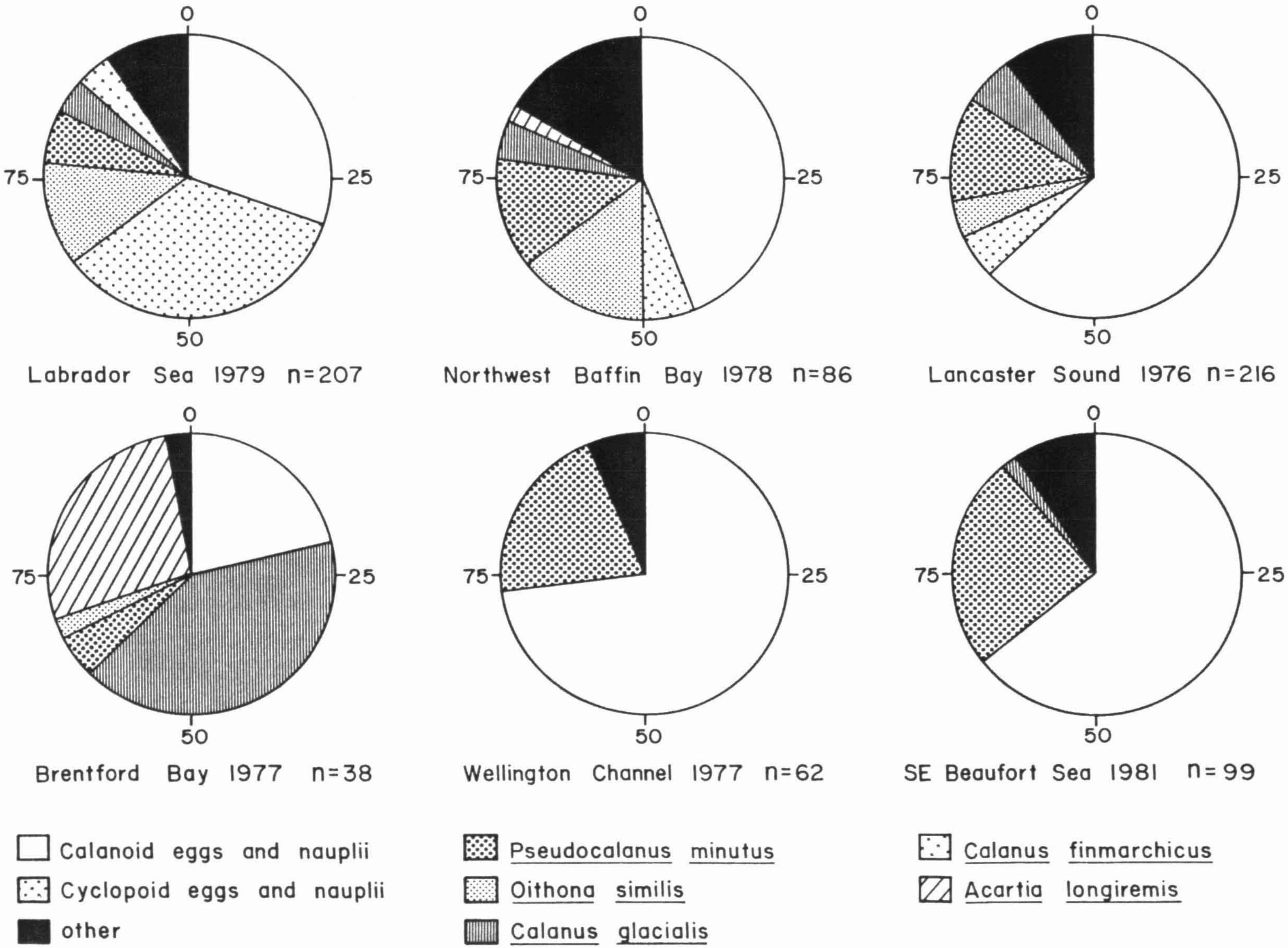


Fig. 9. Percent composition of the diets of Y-O-Y Arctic cod collected in six areas.

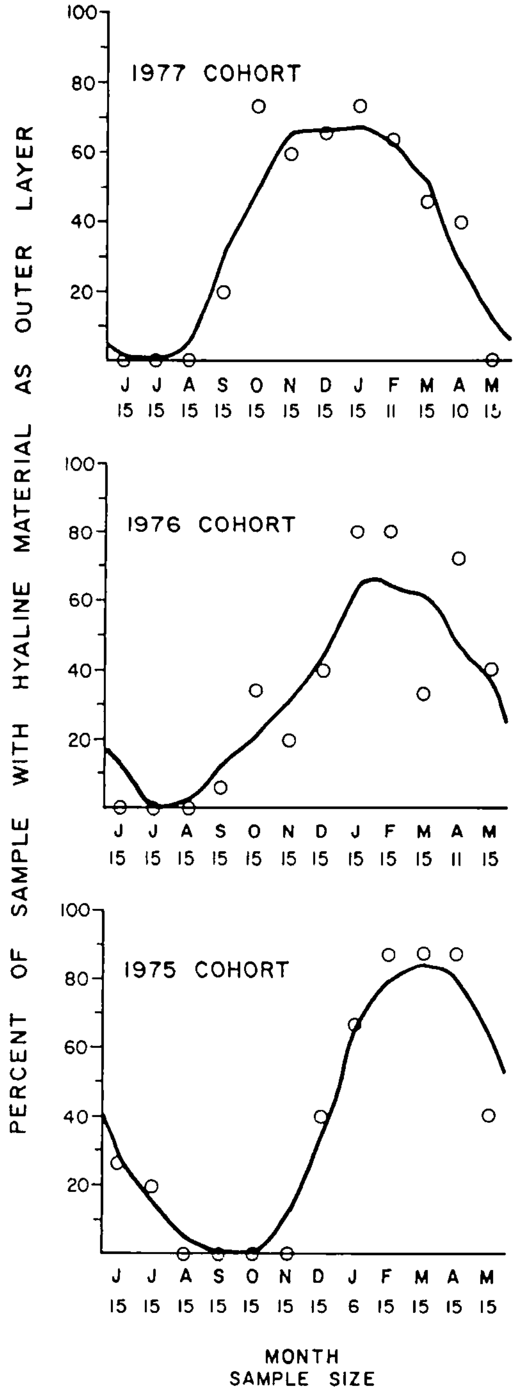


Fig. 10. Pattern of deposition of outer hyaline layer (annular ring) in Arctic cod otoliths. All samples were collected over a consecutive 12-month period (June 1978 to May 1979) from ringed seal stomachs and feces obtained in Pond Inlet. Curves are three-month moving averages for three cohorts (defined by year of hatching). The 1977 cohort was 1+ years old in June 1978 and 2+ years old in May 1979. The 1976 and 1975 cohorts were 2+ and 3+ years old in June 1978, respectively. Actual monthly percentages are indicated by circles.

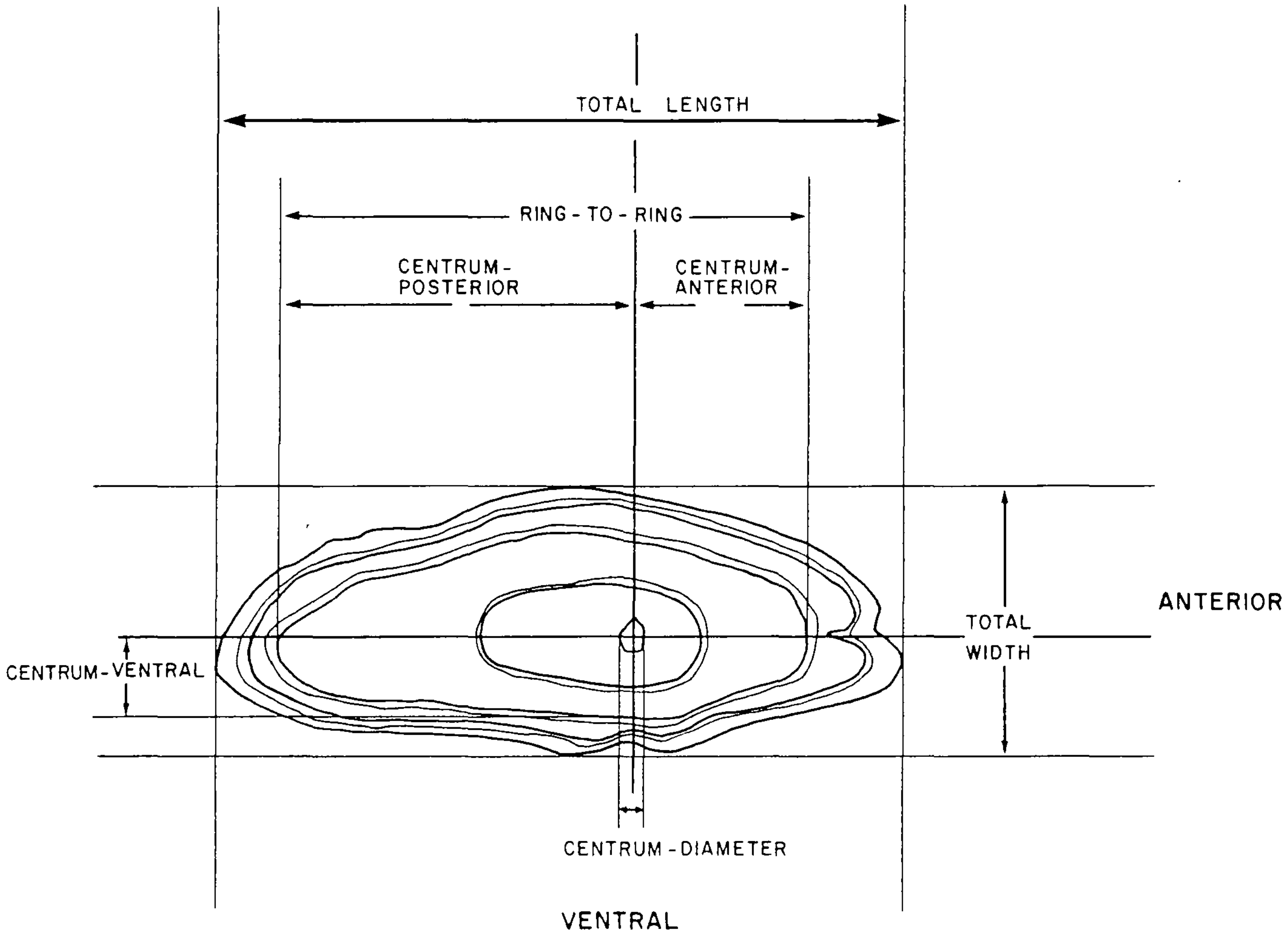
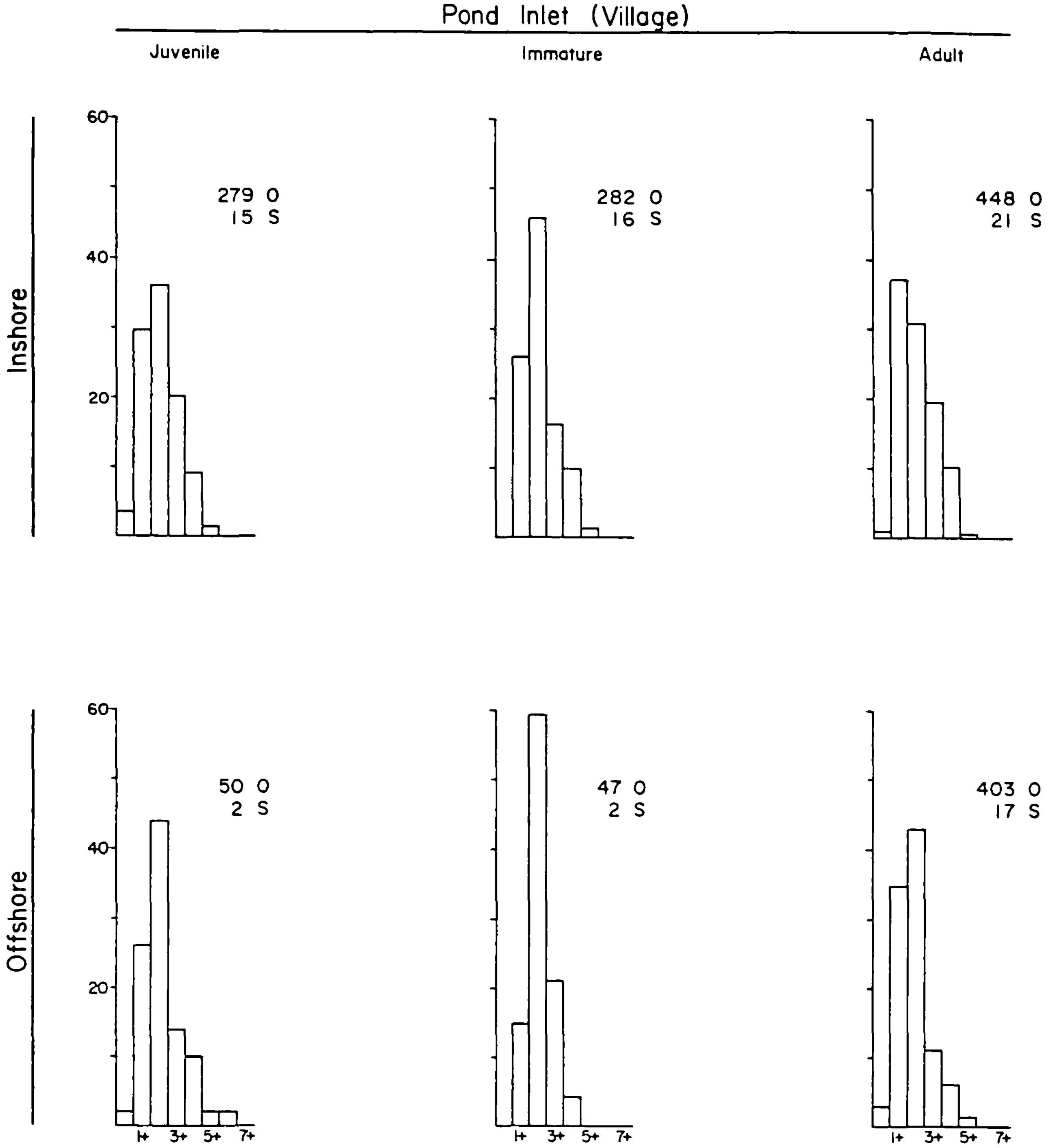


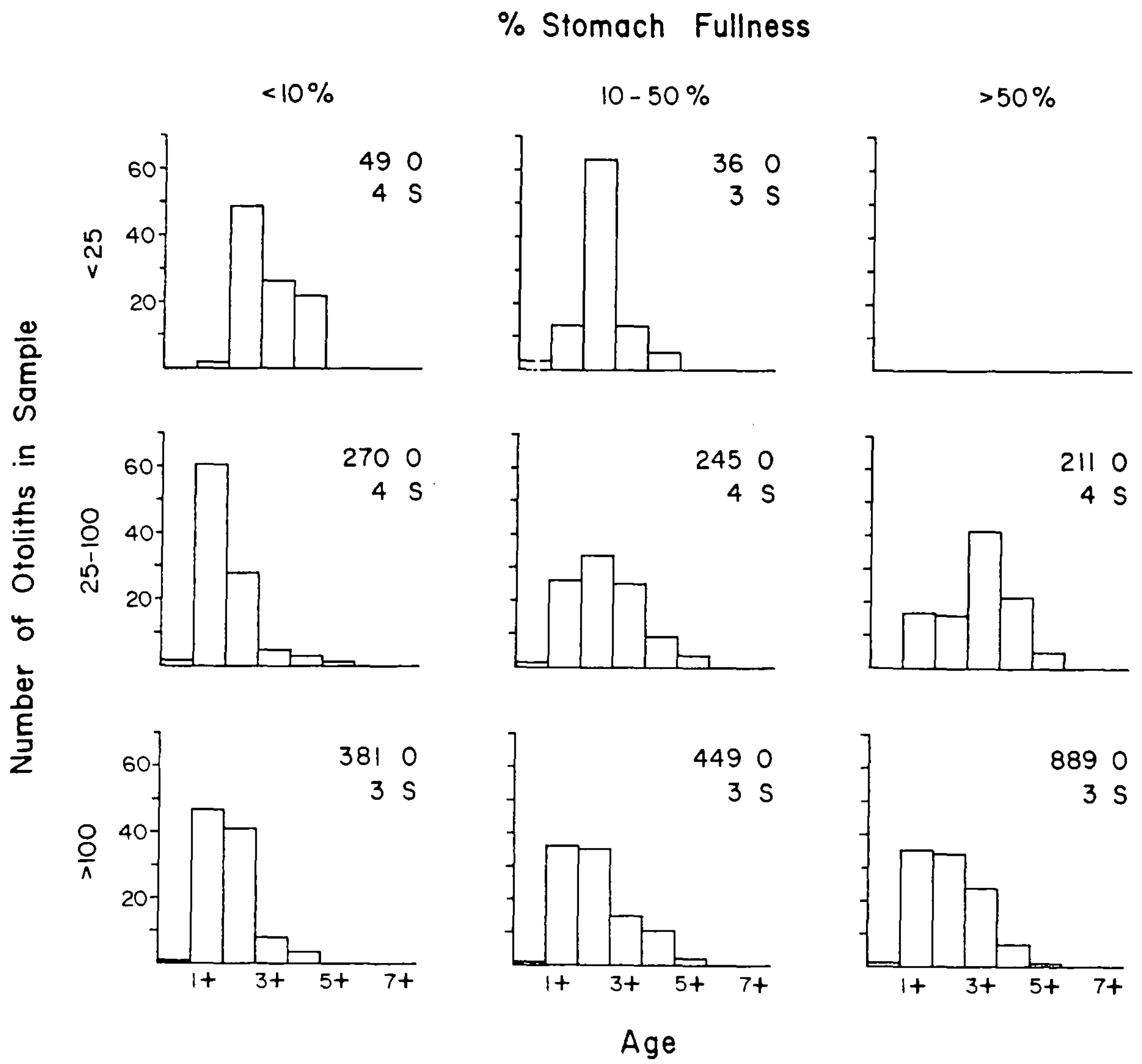
Fig. 11. Lateral view of right otolith of an Arctic cod showing otolith measurements made in this study. Narrow concentric rings are hyaline layers, broad concentric rings are opaque layers.



Mean Otolith Ages ± s.d.

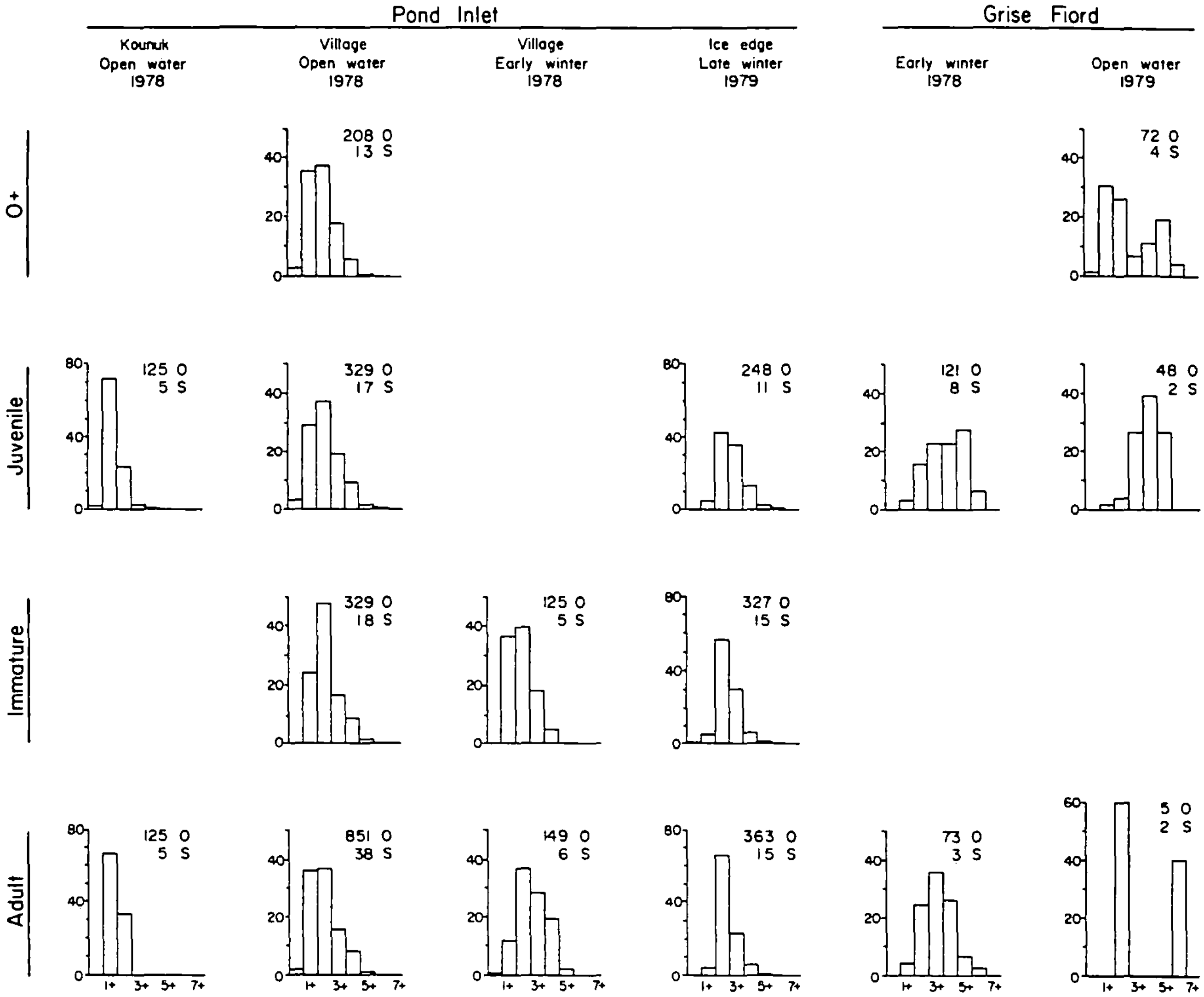
	Juvenile	Immature	Adult
Inshore	2.1 ± 1.1	2.1 ± 1.0	2.0 ± 1.0
Offshore	2.2 ± 1.2	2.1 ± 0.7	1.9 ± 1.0

Fig. 12. Age-frequency distributions of Arctic cod otoliths found in three age-classes of ringed seals taken near the village of Pond Inlet during the open-water period (August-October) in 1978. O = number of otoliths, S = number of predator samples. Abscissa is otolith age; ordinate is percent of number of otoliths. All three inshore/offshore comparisons were non-significant (Kolmogorov-Smirnov P>0.1).



Otoliths per Sample	Mean Otolith Ages ± s.d.		
<25	2.7±0.9	2.1 ±0.8	—
25-100	1.5±0.8	2.3 ± 1.1	2.8 ± 1.1
>100	1.7±0.8	2.0 ± 1.1	2.0±0.9

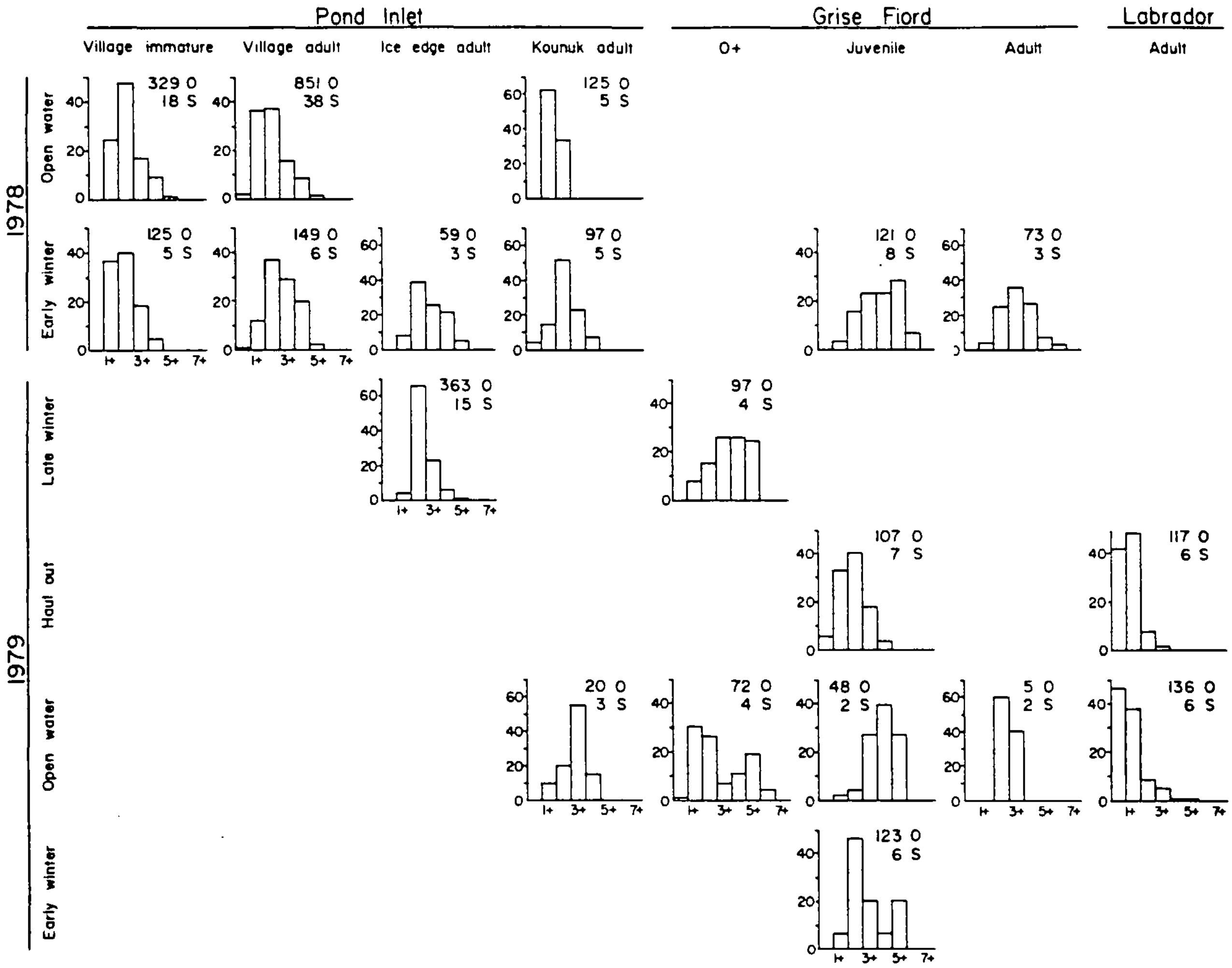
Fig. 13. Age-frequency distributions of Arctic cod otoliths found in ringed seal samples collected near the village of Pond Inlet during the open water season, 1978. Samples are organized by % stomach fullness (estimated visually when the stomach was examined in the field) and by number of otoliths in the sample. All otoliths in the 28 samples were used. O = number of otoliths, S = number of predator samples. Abscissa is otolith age; ordinate is percent of number of otoliths. There were no significant differences in the age distribution of otoliths either within or among categories of stomach fullness, regardless of the number of otoliths present in the stomachs (all Kolmogorov--Smirnov P>0.1). Lack of significance in the comparisons of distributions with <10% stomach fullness may have been due to small sample sizes.



Mean Otolith Ages ± s.d.

0^+	—	1.9 ± 1.0	—	—	—	2.7 ± 1.7
Juvenile	1.3 ± 0.6	2.1 ± 1.1	—	2.7 ± 0.9	3.8 ± 1.3	3.9 ± 0.9
Immature	—	2.1 ± 0.9	1.9 ± 0.9	2.4 ± 0.7	—	—
Adult	1.3 ± 0.5	2.0 ± 1.0	2.6 ± 1.0	2.3 ± 0.7	3.2 ± 1.1	3.6 ± 2.2

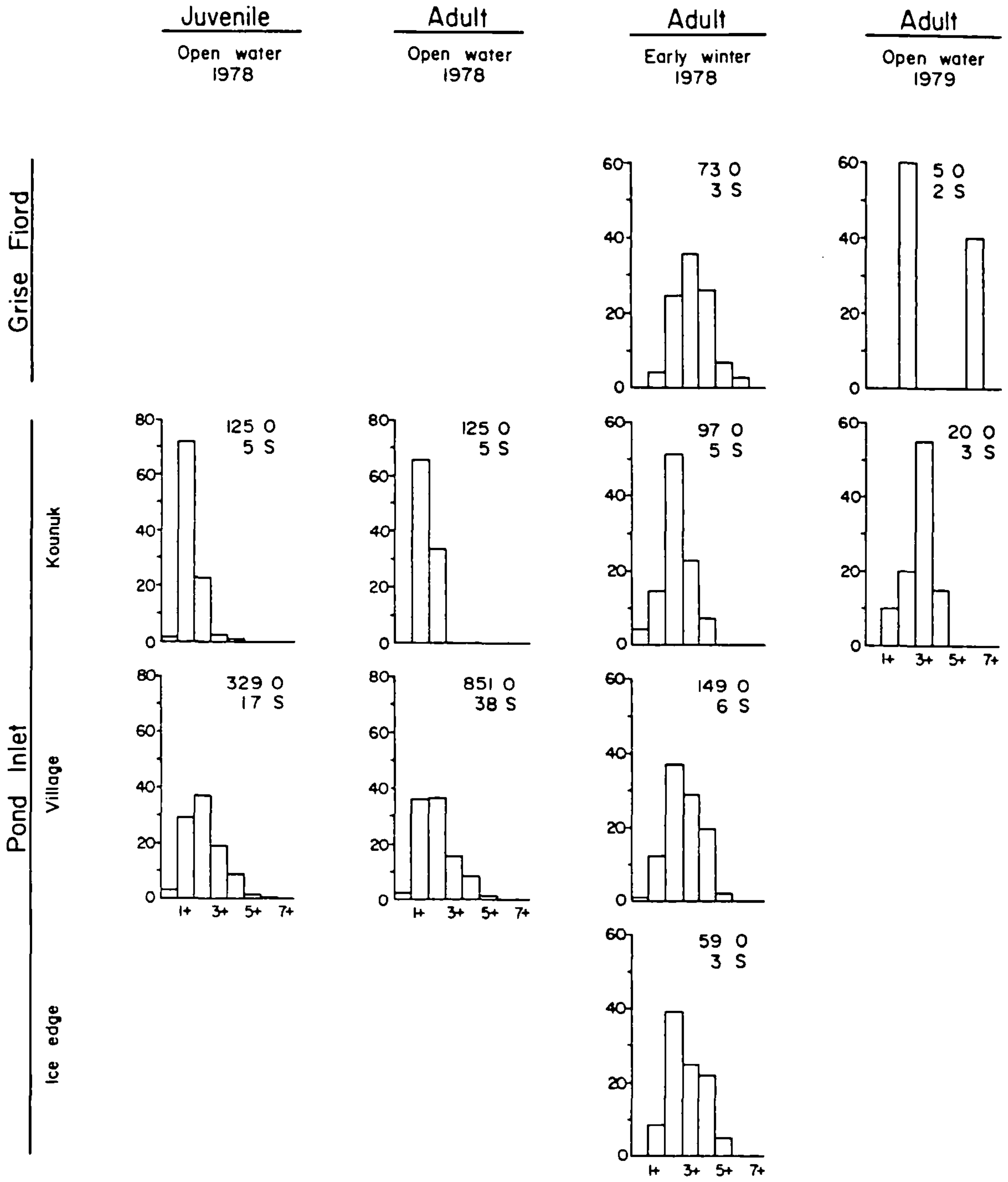
Fig. 14. Age-frequency distributions of Arctic cod otoliths found in 0+, juvenile, immature and adult ringed seal samples taken at various locations and in various seasons. 0 = number of otoliths, S = number of predator samples. Abscissa is otolith age; ordinate is percent of number of otoliths. There were no significant differences in the age-frequency distributions in any of the 15 possible comparisons (all Kolmogorov-Smirnov P>0.1).



Mean Otolith Ages ± s.d.

1978								
Open water	2.1 ±0.9	2.0 ± 1.0	—	1.3 ± 0.5	—	—	—	—
Early winter	1.9±0.9	2.6 ± 1.0	2.8 ± 1.1	2.1 ± 0.9	—	3.8 ± 1.3	3.2 ± 1.1	—
1979								
Late winter	—	—	2.3 ±0.7	—	3.4 ± 1.2	—	—	—
Haul out	—	—	—	—	—	1.8 ± 0.9	—	0.7 ± 0.7
Open water	—	—	—	2.8 ± 0.9	2.7 ± 1.7	3.9 ± 0.9	3.6 ± 2.2	0.8 ± 0.9
Early winter	—	—	—	—	—	2.9 ± 1.3	—	—

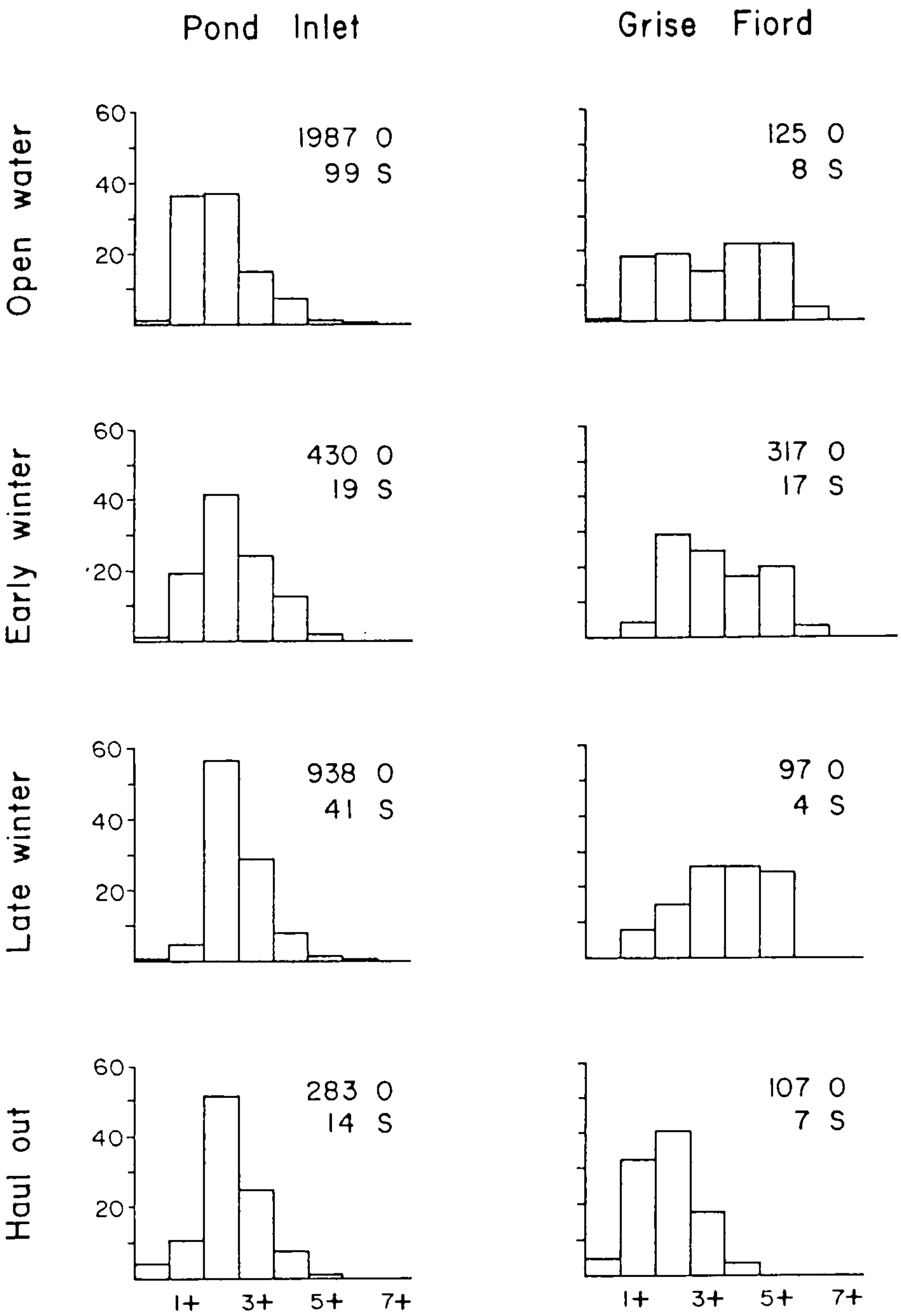
Fig. 15. Age-frequency distributions of Arctic cod otoliths found in samples from ringed seals of the same age and collection location, but different seasons and years. O = number of otoliths, S = number of predator samples. Abscissa is otolith age; ordinate is percent of number of otoliths. There were no significant differences in age-frequency distributions of Arctic cod otoliths in any of the 15 possible comparisons involving these samples (all Kolmogorov-Smirnov P>0.1).



Mean Otolith Ages ± s.d.

Grise Fiord	—	—	3.2 ± 1.1	3.6 ± 2.2
Pond Inlet				
Kounuk	1.3 ± 0.6	2.8 ± 0.9	2.1 ± 0.9	2.8 ± 0.9
Village	2.1 ± 1.1	2.0 ± 1.0	2.6 ± 1.0	—
Ice edge	—	—	2.8 ± 1.1	—

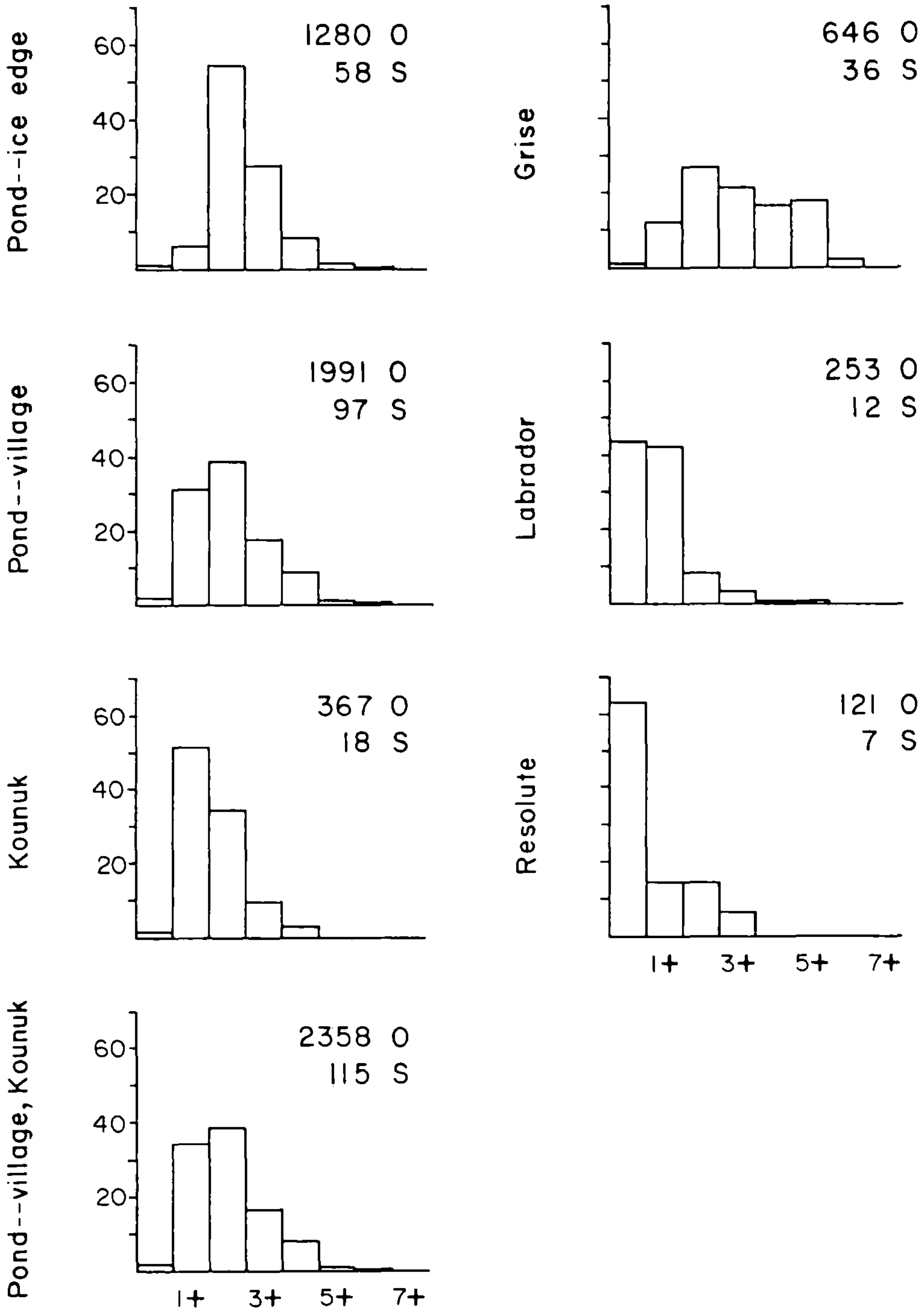
Fig. 16. Age-frequency distributions of Arctic cod otoliths found in samples from ringed seals taken in different locations. O = number of otoliths, S = number of predator samples. Abscissa is otolith age; ordinate is percent of number of otoliths. There were no significant differences in age-frequency distributions of Arctic cod otoliths in any of the nine possible comparisons involving these samples (all Kolmogorov-Smirnov P>0.1).



Mean Otolith Ages ± s.d.

Open water	2.4 ± 1.0	3.7 ± 1.6
Early winter	2.8 ± 1.0	3.8 ± 1.3
Late winter	2.9 ± 0.8	3.9 ± 1.3
Haul out	2.7 ± 0.9	2.3 ± 0.9

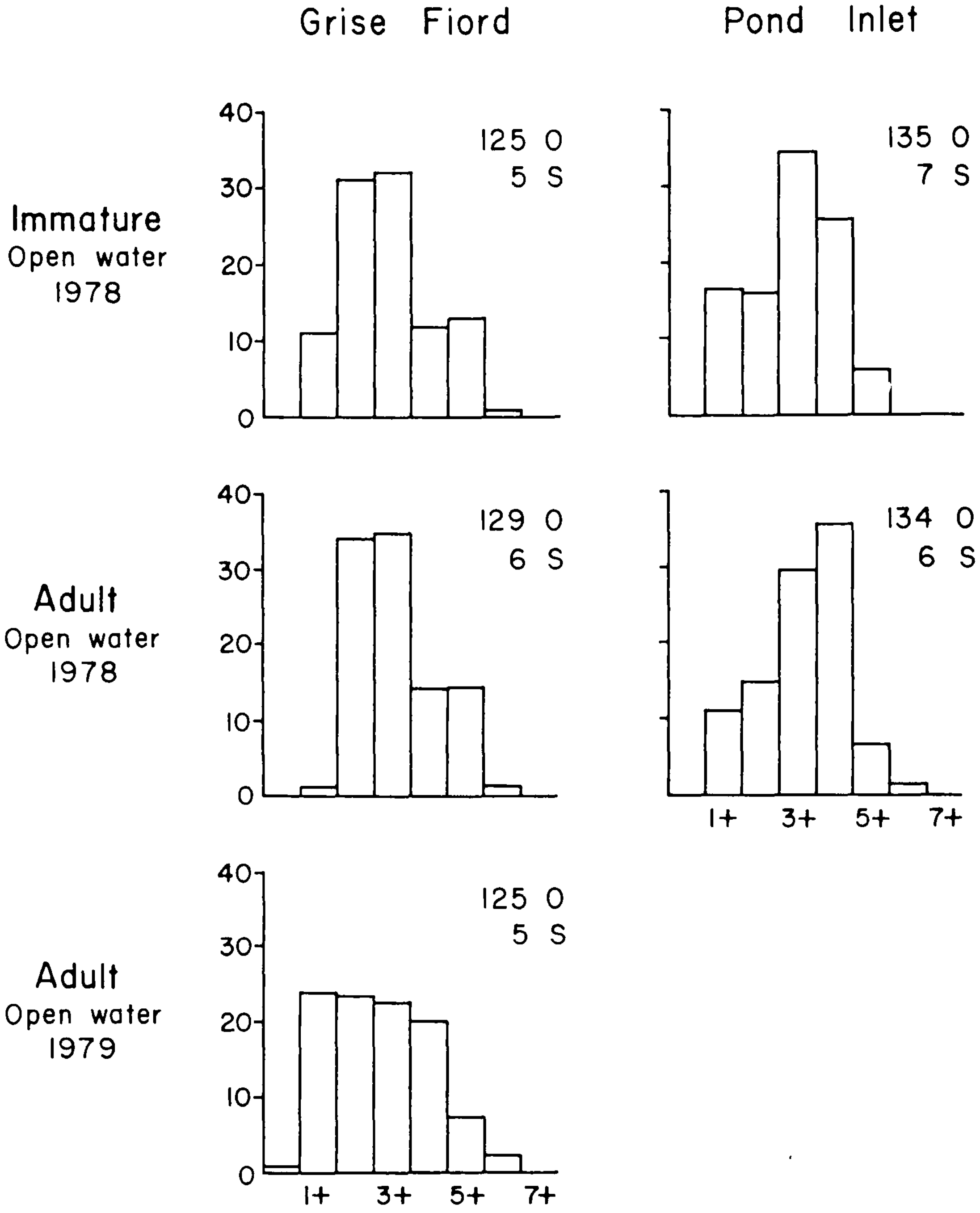
Fig. 17. Age-frequency distributions of Arctic cod otoliths found in samples from ringed seals taken in different seasons. Samples taken in the same seasons in different years were combined. O = number of otoliths, S = number of predator samples. Abscissa is otolith age; ordinate is percent of number of otoliths.



Mean Otolith Ages ± s.d.

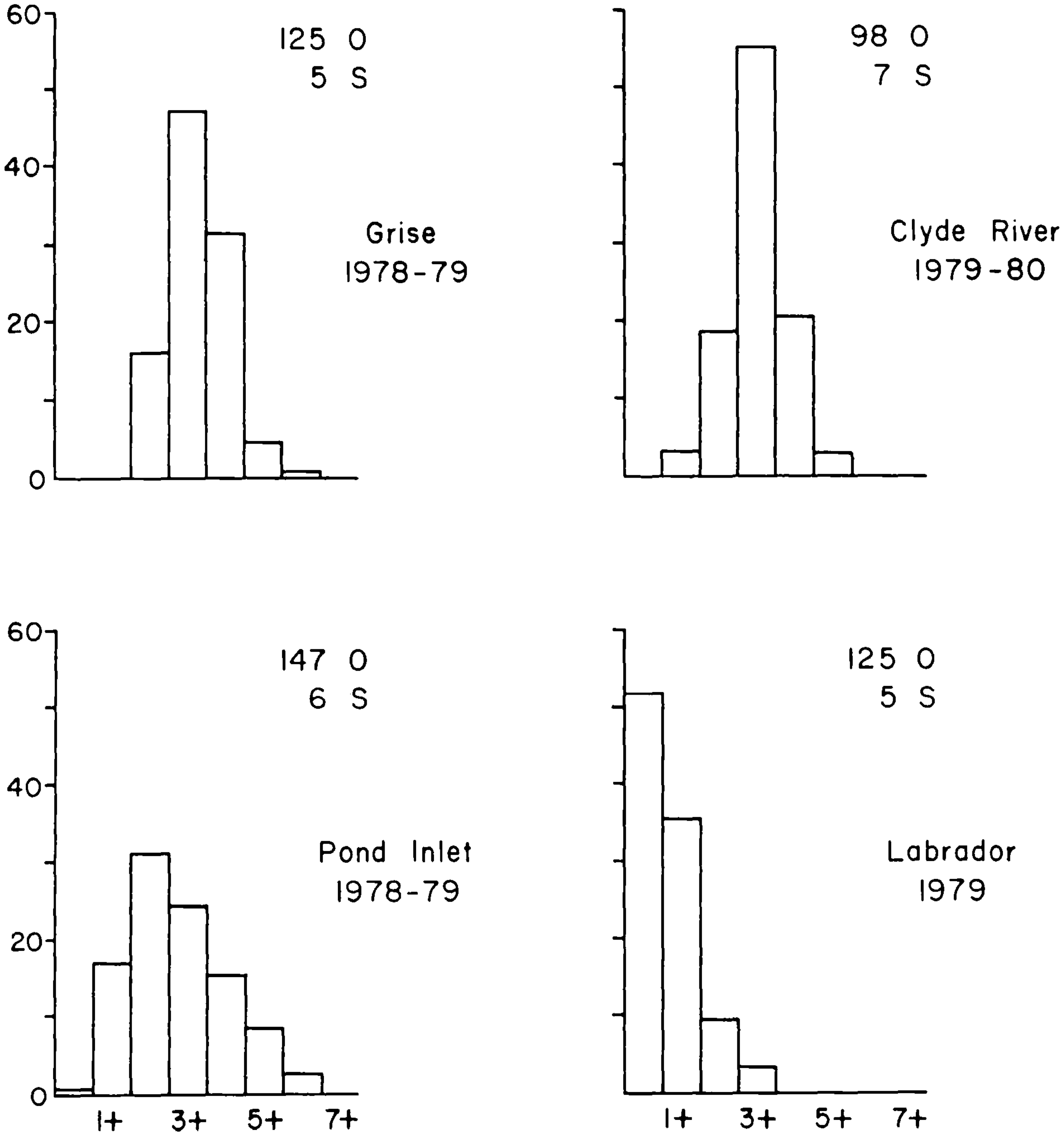
Pond--ice edge	2.9 ± 0.8	Grise	3.5 ± 1.4
Pond--village	2.6 ± 1.0	Labrador	1.2 ± 0.8
Pond--Kounuk	2.1 ± 0.8	Resolute	1.1 ± 1.0
Pond--village, Kounuk	2.5 ± 1.0		

Fig. 18. Age-frequency distributions of Arctic cod otoliths found in samples from ringed seals taken in different areas. Samples taken in all seasons and years were combined. O = number of otoliths, S = number of predator samples. Abscissa is otolith age; ordinate is percent of number of otoliths.



		Mean Otolith Ages ± s.d.	
Immature	1978	2.9±1.2	2.9±1.2
Adult	1978	3.1±1.1	3.2±1.2
Adult	1979	2.7±1.4	—

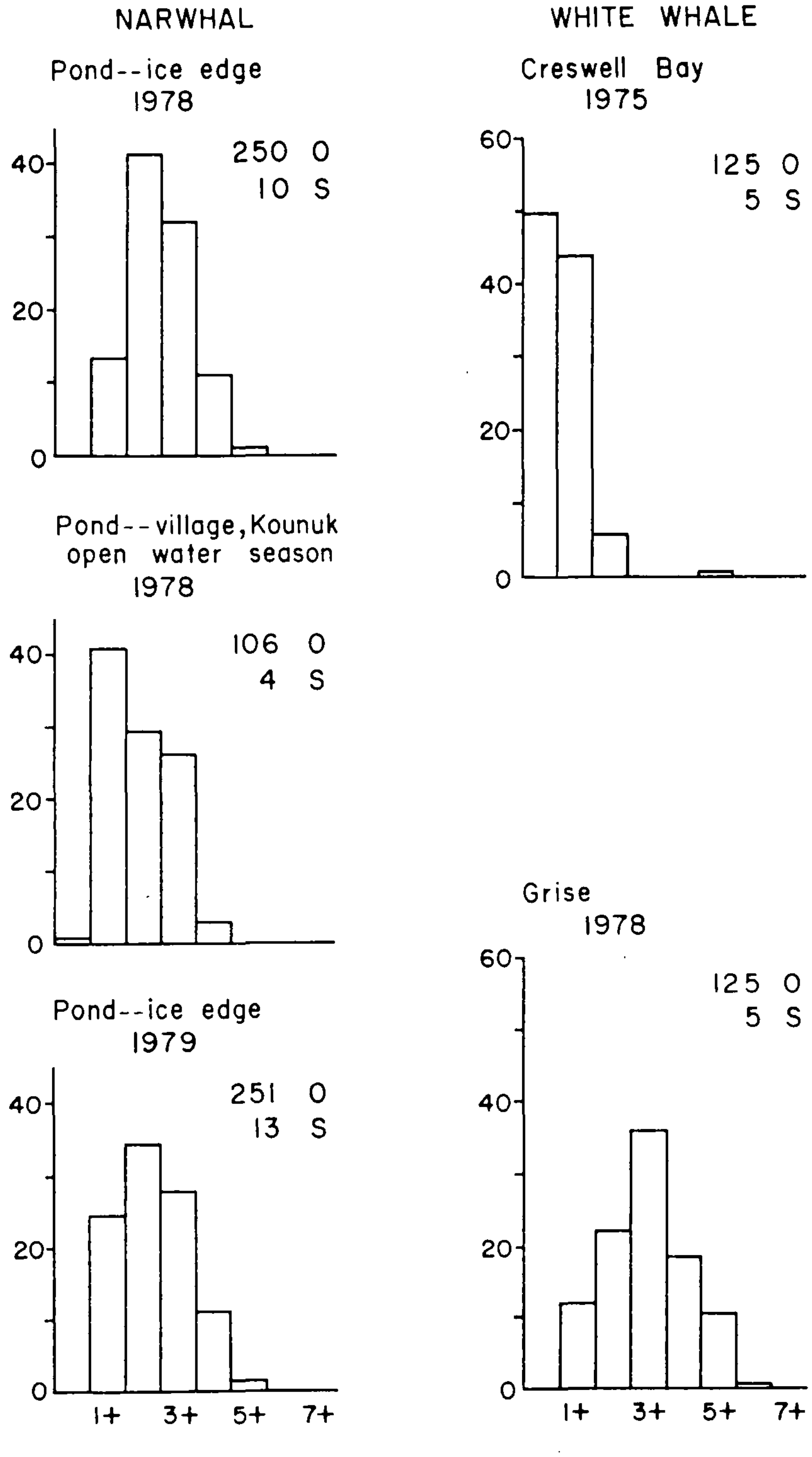
Fig. 19. Age-frequency distributions of Arctic cod otoliths found in harp seal samples taken during the open-water periods, 1978-79, at Grise Fiord and Pond Inlet. O = number of otoliths, S = number of predator samples. Abscissa is otolith age; ordinate is percent of number of otoliths.



Mean Otolith Ages ± s.d.

Grise	3.3±0.8	Clyde	3.0±0.8
Pond	2.7±1.3	Labrador	0.6±0.8

Fig. 20. Age-frequency distributions of Arctic cod otoliths found in bearded seal samples taken during the open-water periods, 1978-80. O = number of otoliths, S = number of predator samples. Abscissa is otolith age; ordinate is percent of number of otoliths.



Mean Otolith Ages ± s.d.			
Pond--ice edge 1978	3.0 ± 0.9	Creswell Bay	1.1 ± 0.7
Pond--village, Kounuk	2.4 ± 0.9	Grise	3.5 ± 1.2
Pond--ice edge 1979	2.8 ± 1.0		

Fig. 21. Age-frequency distributions of Arctic cod otoliths found in narwhal and white whale samples from Pond Inlet, 1978-79. O = number of otoliths, S = number of predator samples. Abscissa is otolith age; ordinate is percent of number of otoliths.

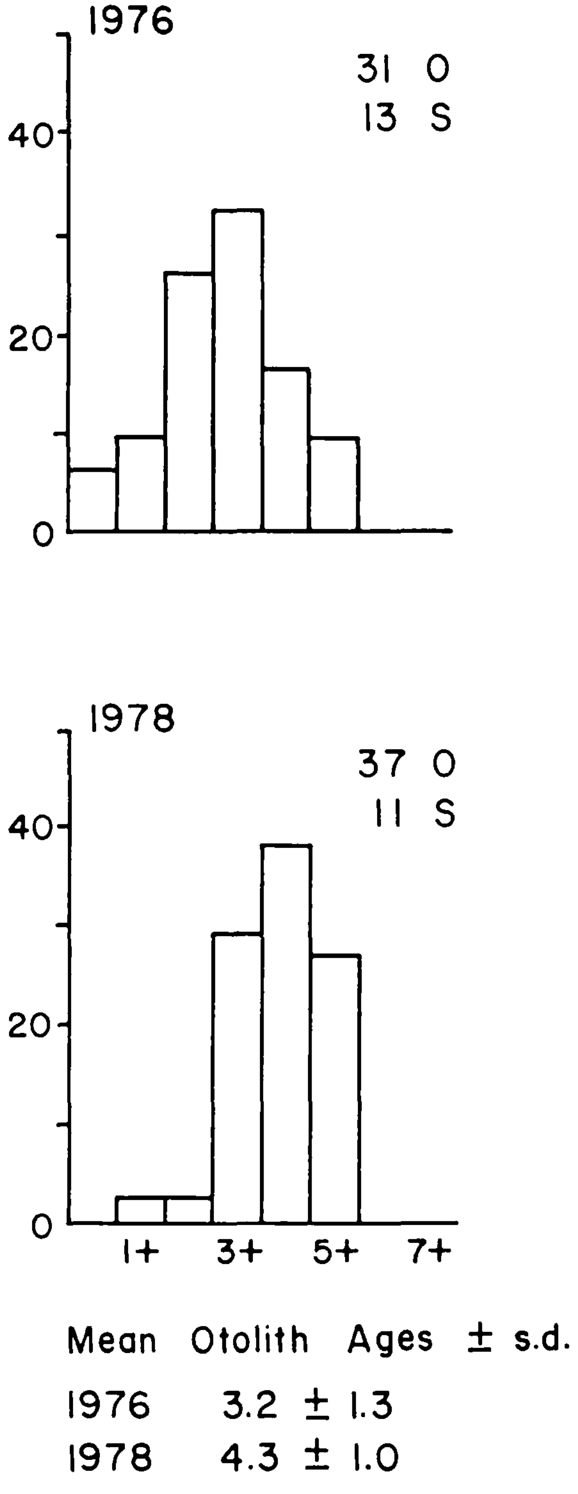
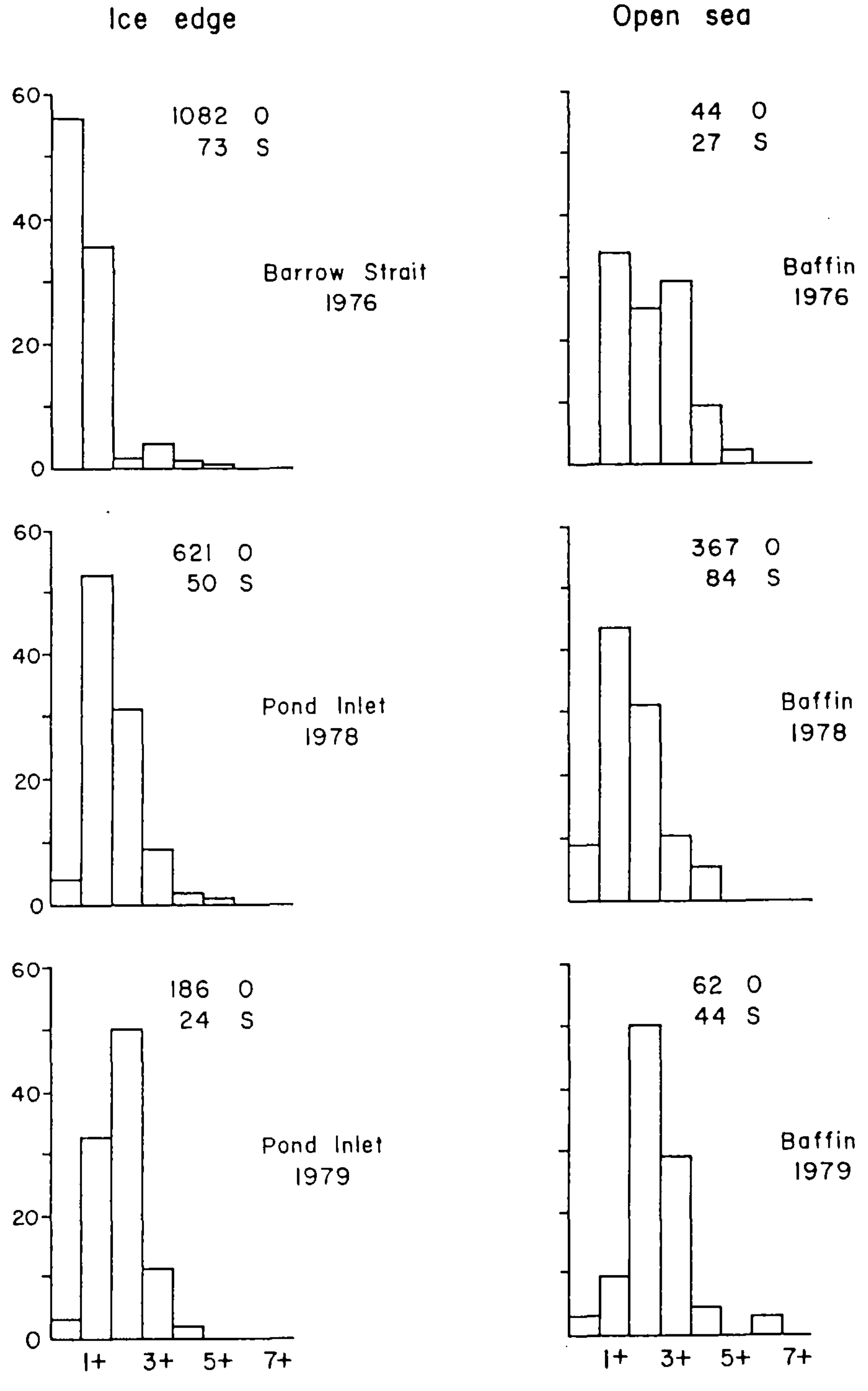


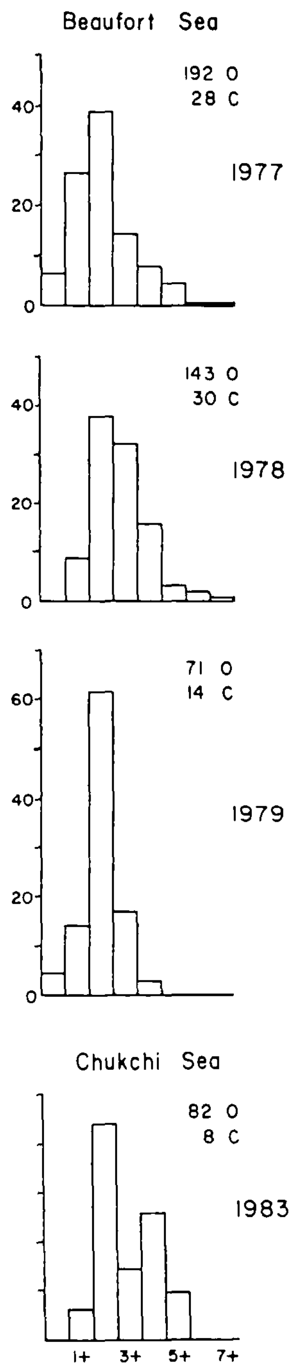
Fig. 22. Age-frequency distributions of Arctic cod otoliths found in samples from northern fulmars collected in northwest Baffin Bay and Lancaster Sound in 1976 and 1978. O = number of otoliths, S = number of predator samples. Abscissa is otolith age; ordinate is percent of number of otoliths.



Mean Otolith Ages ± s.d.

Barrow Strait 1976	0.6±0.9	Baffin 1976	2.2±1.1
Pond Inlet 1978	1.5±0.8	Baffin 1978	1.6±1.0
Pond Inlet 1979	1.8±0.8	Baffin 1979	2.4±1.1

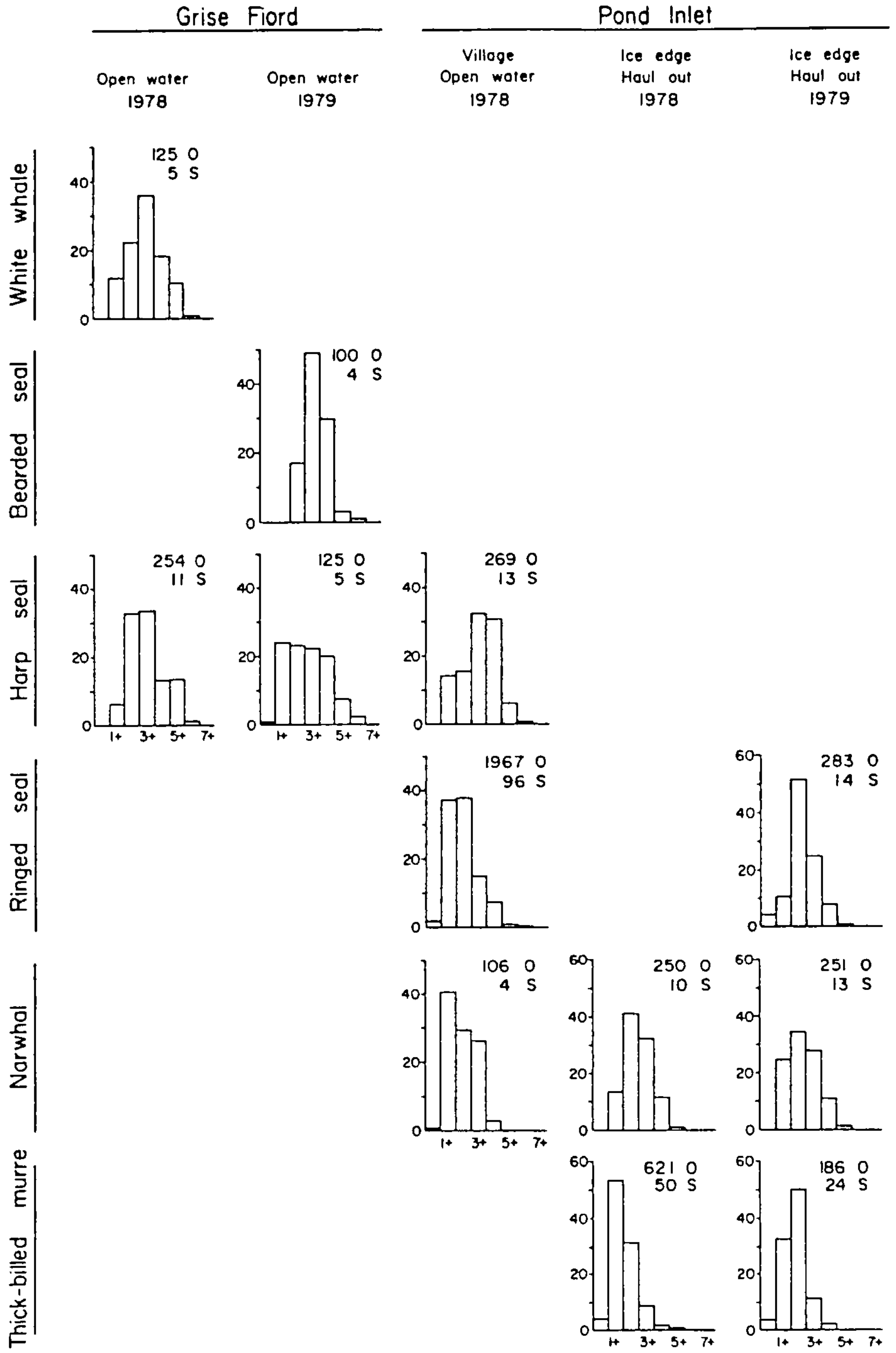
Fig. 23. Age-frequency distributions of Arctic cod otoliths found in samples from thick-billed murres collected in various areas and years. O = number of otoliths, S = number of predator samples. Abscissa is otolith age; ordinate is percent of number of otoliths.



Mean Otolith Ages ± s.d.

1977 2.1 ± 1.3
1978 2.8 ± 1.1
1979 2.0 ± 0.8
1983 2.9 ± 1.2

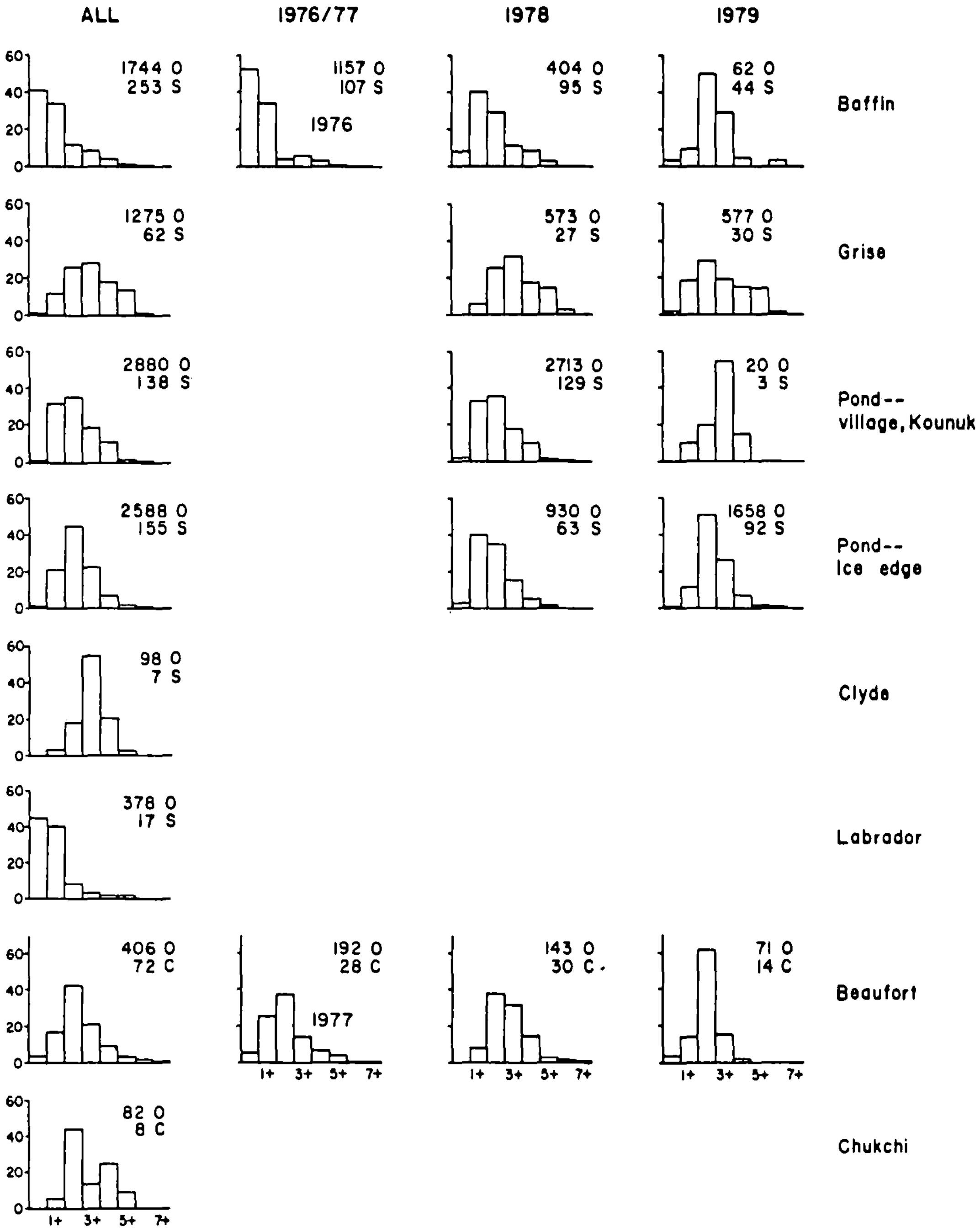
Fig. 24. Age-frequency distributions of otoliths taken from whole Arctic cod collected in the Beaufort and Chukchi seas. 0 = number of otoliths, C = number of collections. Abscissa is otolith age; ordinate is percent of number of otoliths.



Mean Otolith Ages ± s.d.

WW	3.0 ± 1.2	—	—	—	—
BS	—	3.7 ± 0.8	—	—	—
HS	3.5 ± 1.2	2.7 ± 1.4	3.5 ± 1.2	—	—
RS	—	—	2.4 ± 1.0	—	2.2 ± 0.9
NA	—	—	1.9 ± 0.9	2.5 ± 0.9	2.3 ± 1.0
TM	—	—	—	1.5 ± 0.8	1.8 ± 0.8

Fig. 25. Age-frequency distributions of Arctic cod otoliths taken from different predators collected at the same time and location. O = number of otoliths, S = number of predator samples. Abscissa is otolith age; ordinate is percent of number of otoliths.



Mean Otolith Ages ± s.d.

1.5 ± 1.2	1.2 ± 1.0	2.3 ± 1.2	2.9 ± 1.1	Baffin
3.5 ± 1.3	—	3.7 ± 1.2	3.3 ± 1.4	Grise
2.6 ± 1.1	—	2.6 ± 1.1	3.3 ± 0.9	Pond--village, Kounuk
2.7 ± 0.9	—	2.4 ± 1.0	2.8 ± 0.9	Pond--ice edge
3.5 ± 0.8	—	—	—	Clyde
1.2 ± 0.8	1.2 ± 0.8	—	—	Labrador
2.8 ± 1.2	2.6 ± 1.3	3.3 ± 1.1	2.5 ± 0.8	Beaufort
3.4 ± 1.2	—	—	—	Chukchi

Fig. 26. Age-frequency distributions of Arctic cod otoliths in various regions and years. O = number of otoliths, S = number of samples, C = number of fish collections. Abscissa is otolith age; ordinate is percent of number of otoliths.

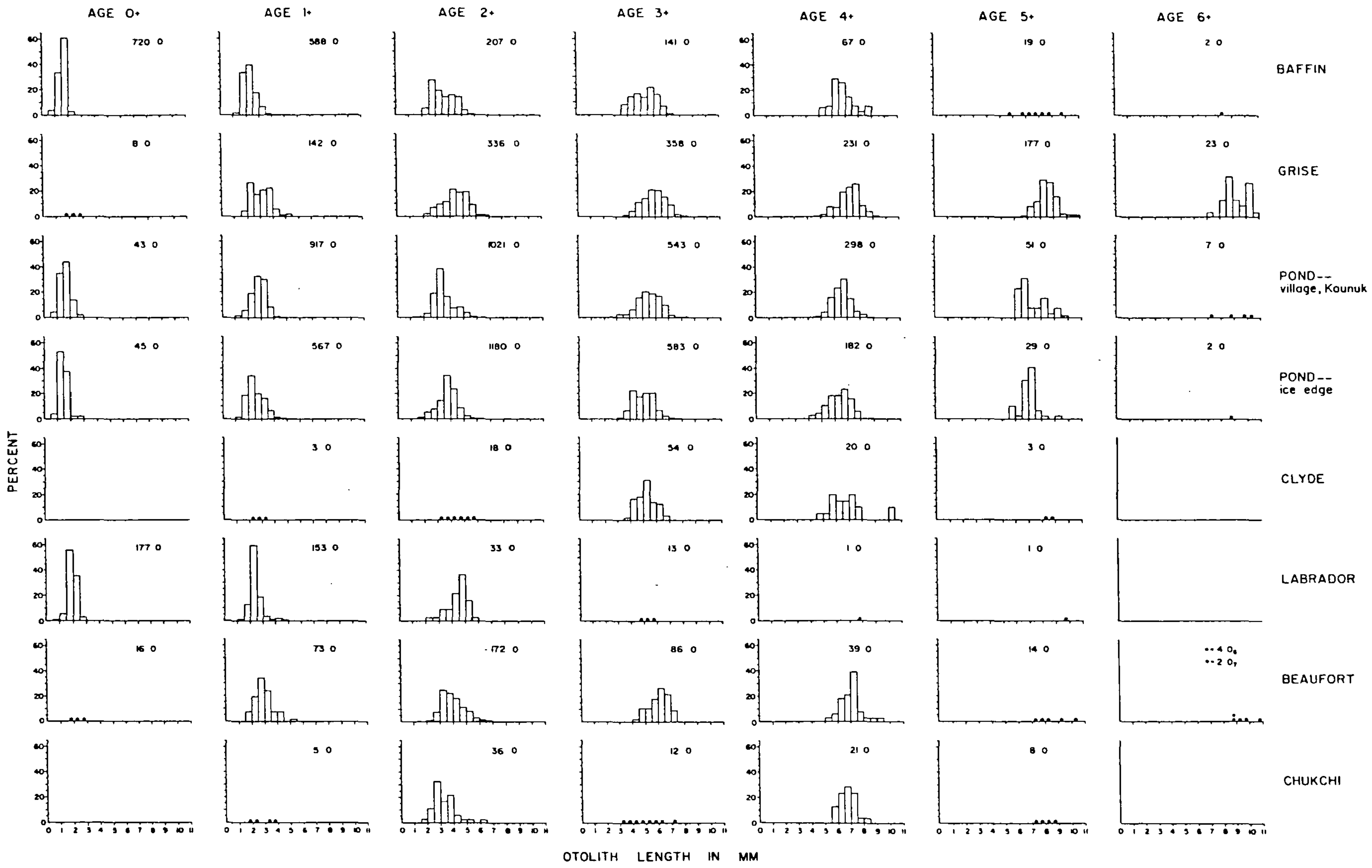


Fig. 27. Length-frequency distributions of seven age classes of Arctic cod otoliths in eight regions. O = number of otoliths. Histograms are plotted if O≥20. When O<20, size distributions of otoliths are indicated with dots along the abscissa. Mean lengths are given in Table 34.

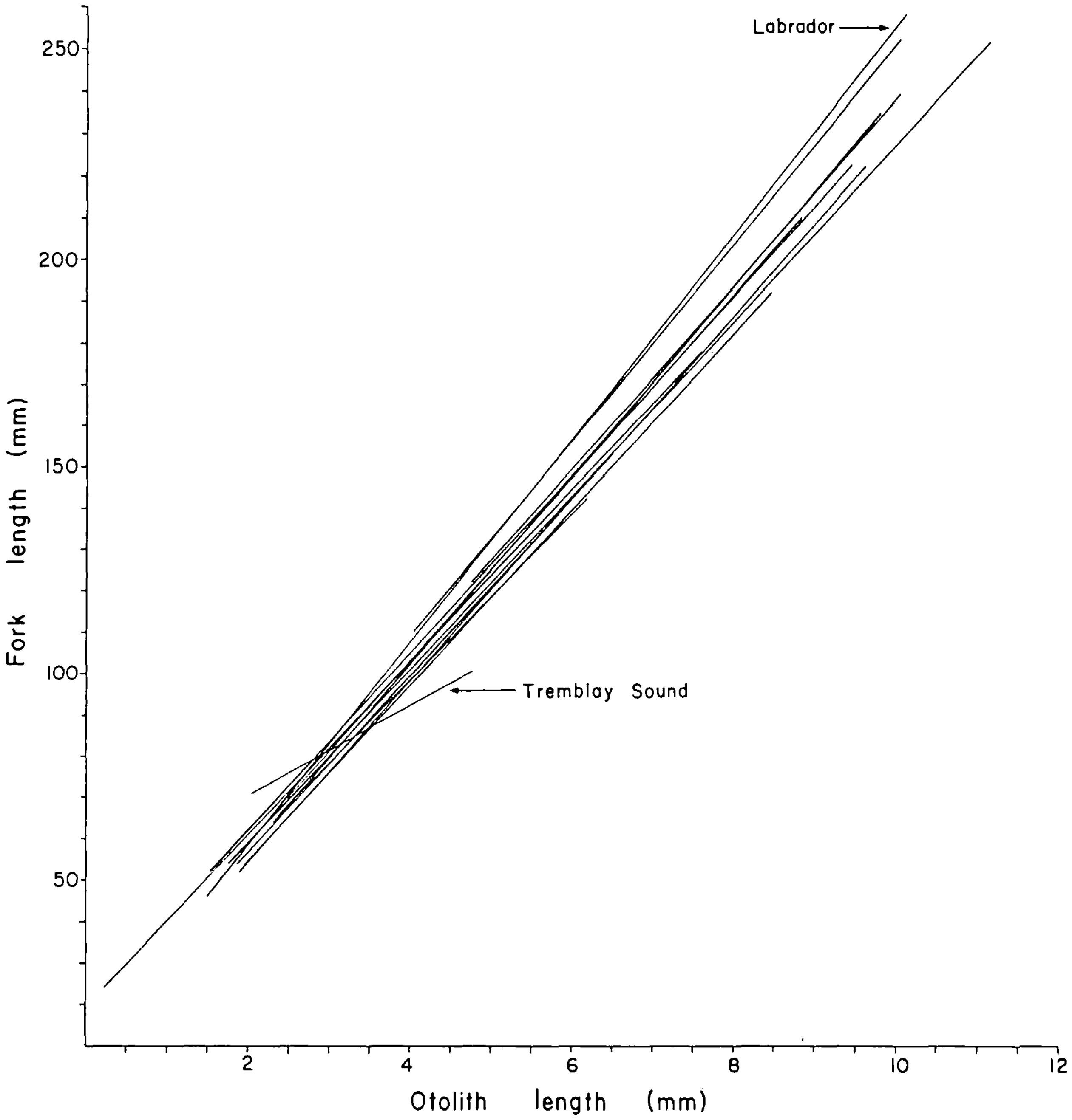


Fig. 28. Otolith length--fork length relationships for 11 collections of Arctic cod. All regressions in Table 23 (except N Bering Sea and Cornwallis Island, July-September 1976) are plotted for the range of fork lengths sampled. Regression slopes for samples from Tremblay Sound and Labrador were most different from the slope calculated for the combined data (22.05).

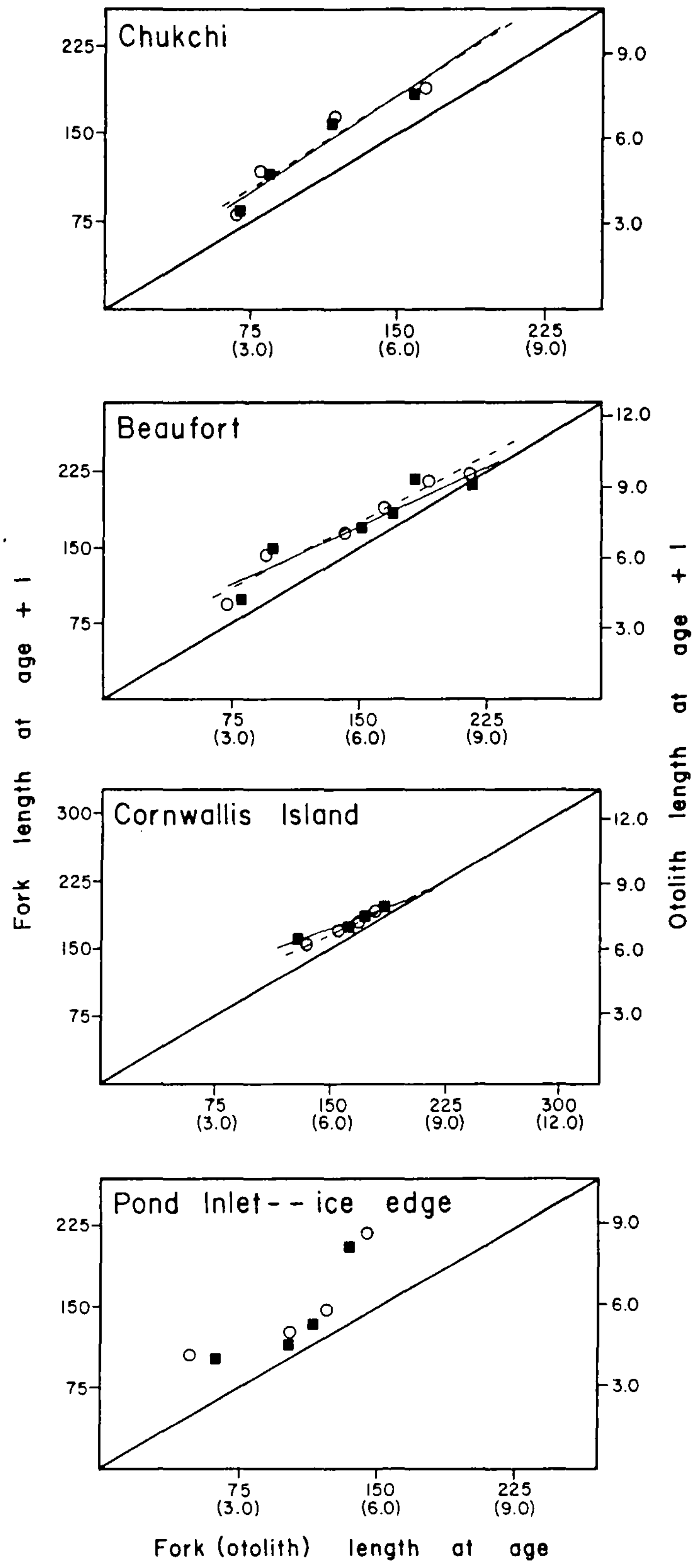


Fig. 29. Walford plots of otolith lengths (circles and dashed lines) and fork lengths (squares and solid lines) from Arctic cod collected in four areas. The two types of data are plotted together to allow a direct comparison of slopes (growth rates). In every instance the first (leftmost) point represents age 2+ plotted against age 1+, and later points proceed in sequence.

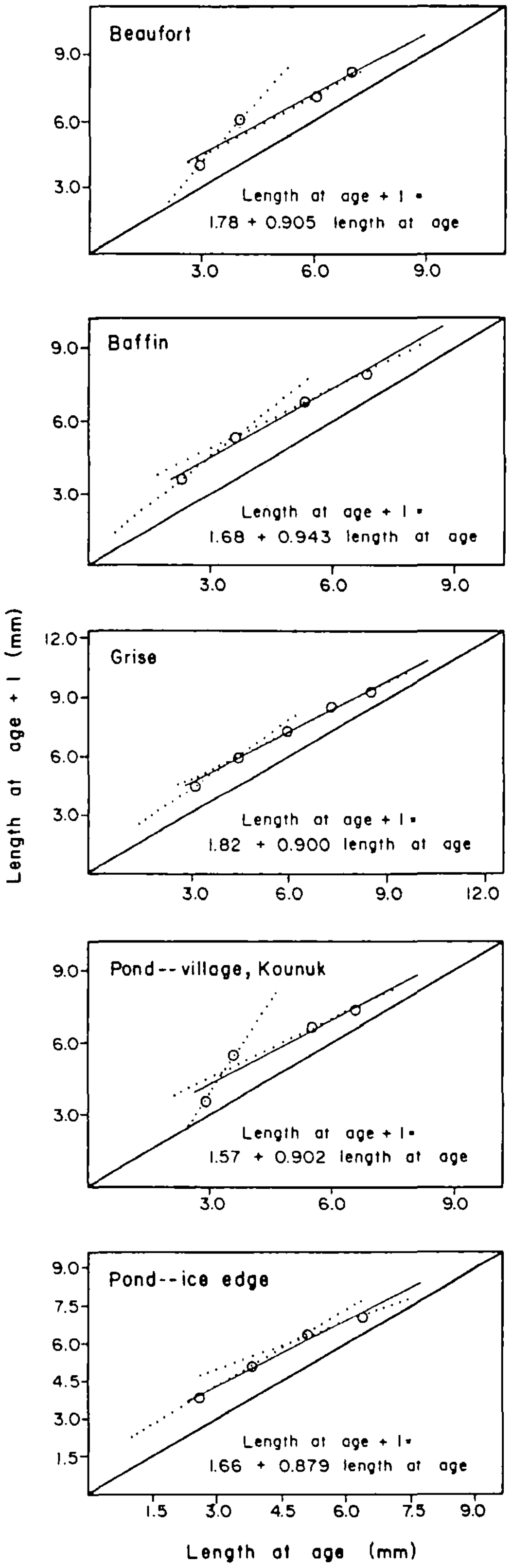


Fig. 30. Walford plots of growth in Arctic cod otoliths. Solid lines and equations are for age classes with n>10. In every instance the first (leftmost) point represents age 2+ plotted against age 1+, and later points proceed in sequence. Dashed lines represent equations fitted to each of two growth stanzas.

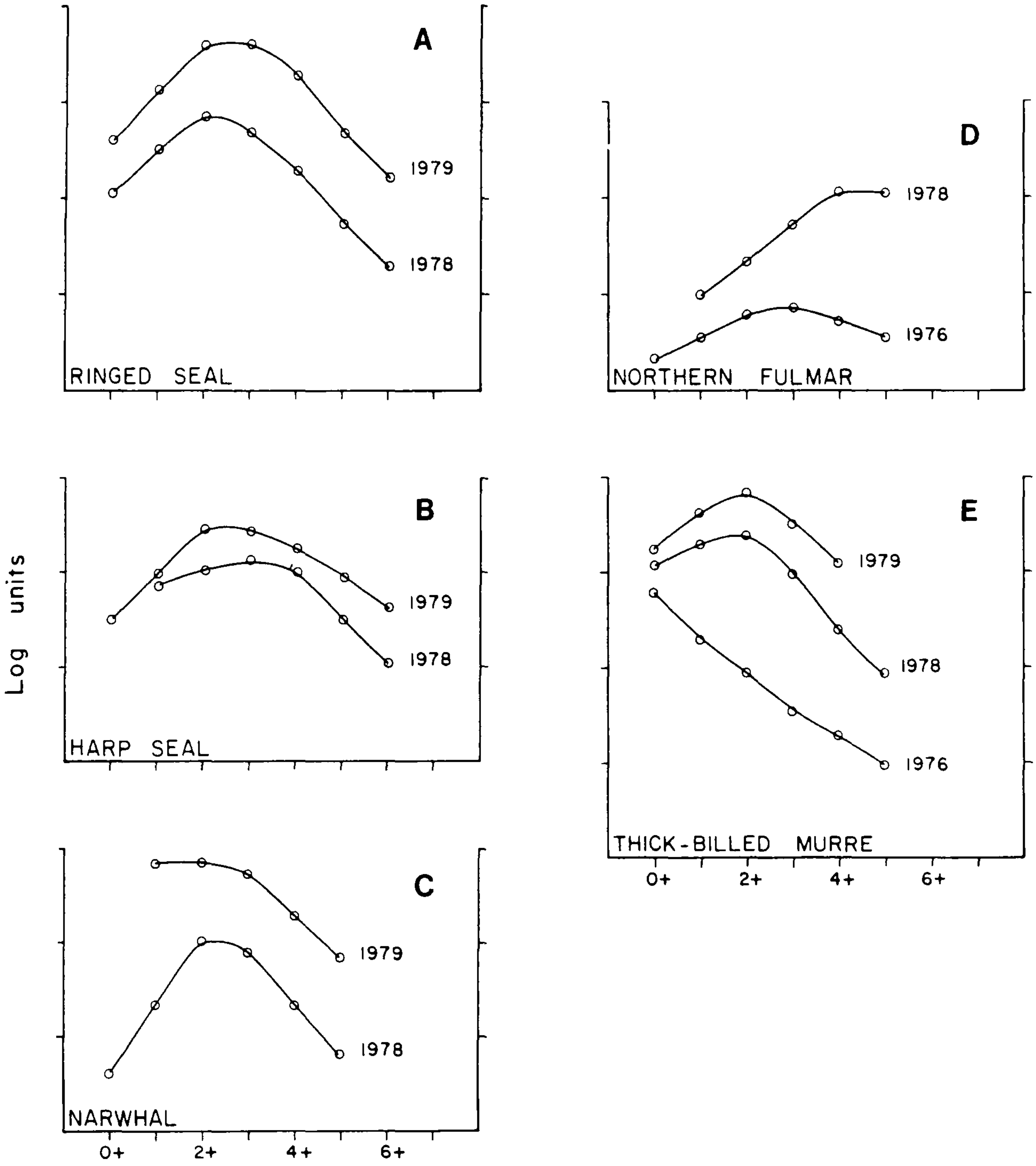


Fig. 31. Catch curves of Arctic cod otoliths in samples from ringed seals (A), harp seals (B), narwhals (C), northern fulmars (D) and thick-billed murres (E) taken during different years. Abscissa is age, ordinate is log units. Values plotted are three-point moving averages. The domes of the curves indicate that cod have been fully recruited into the catchable population at different ages in different years.

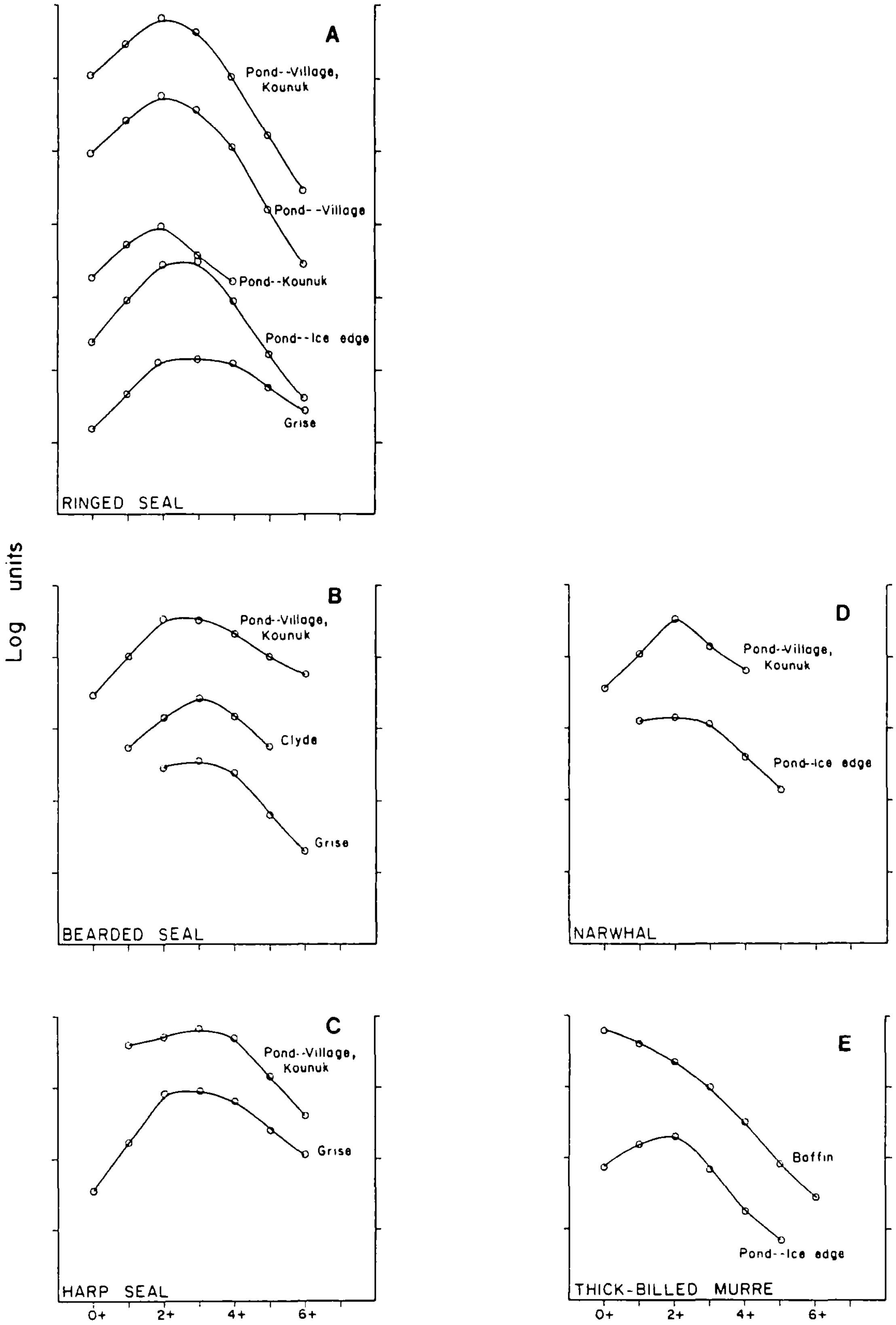


Fig. 32. Catch curves of Arctic cod otoliths in samples from ringed seals (A), bearded seals (B), harp seals (C), narwhals (D) and thick-billed murres (E) taken in different areas during 1978-79. Abscissa is age, ordinate is log units. Values plotted are three-point moving averages.

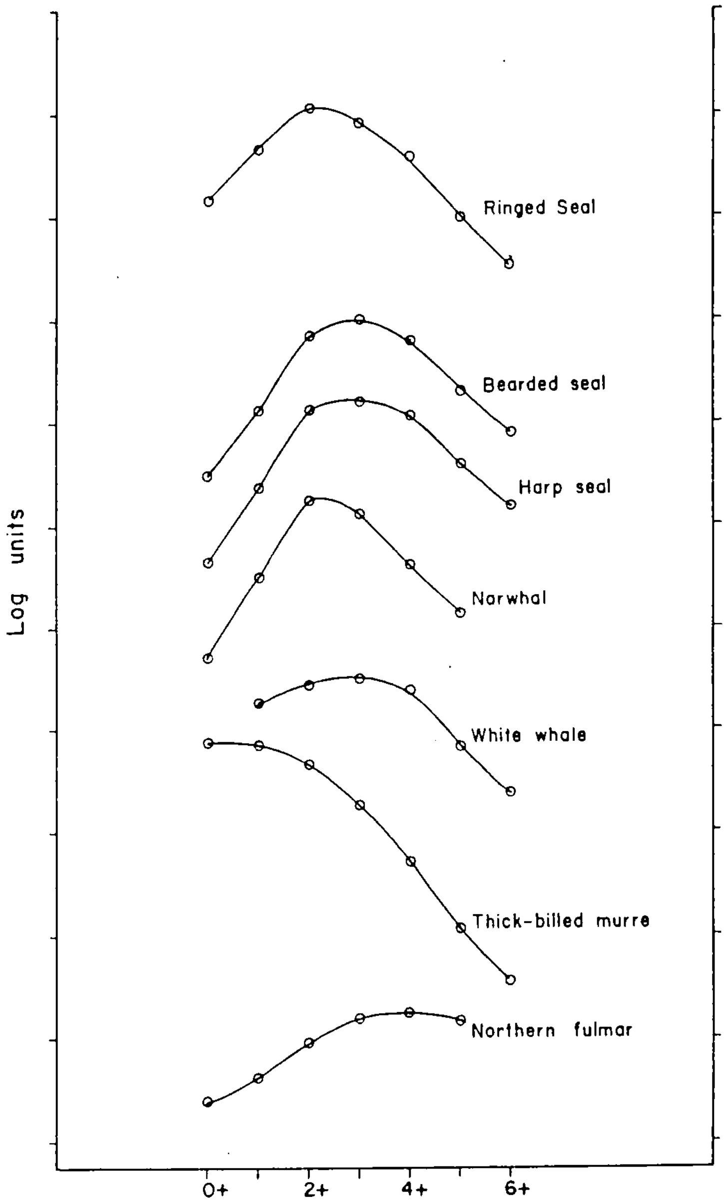


Fig. 33. Catch curves from all samples of predators. Abscissa is age, ordinate is log units. Values plotted are three point moving averages. The right hand limbs of all curves except that for northern fulmar are convex in shape, indicating increasing mortality with age.

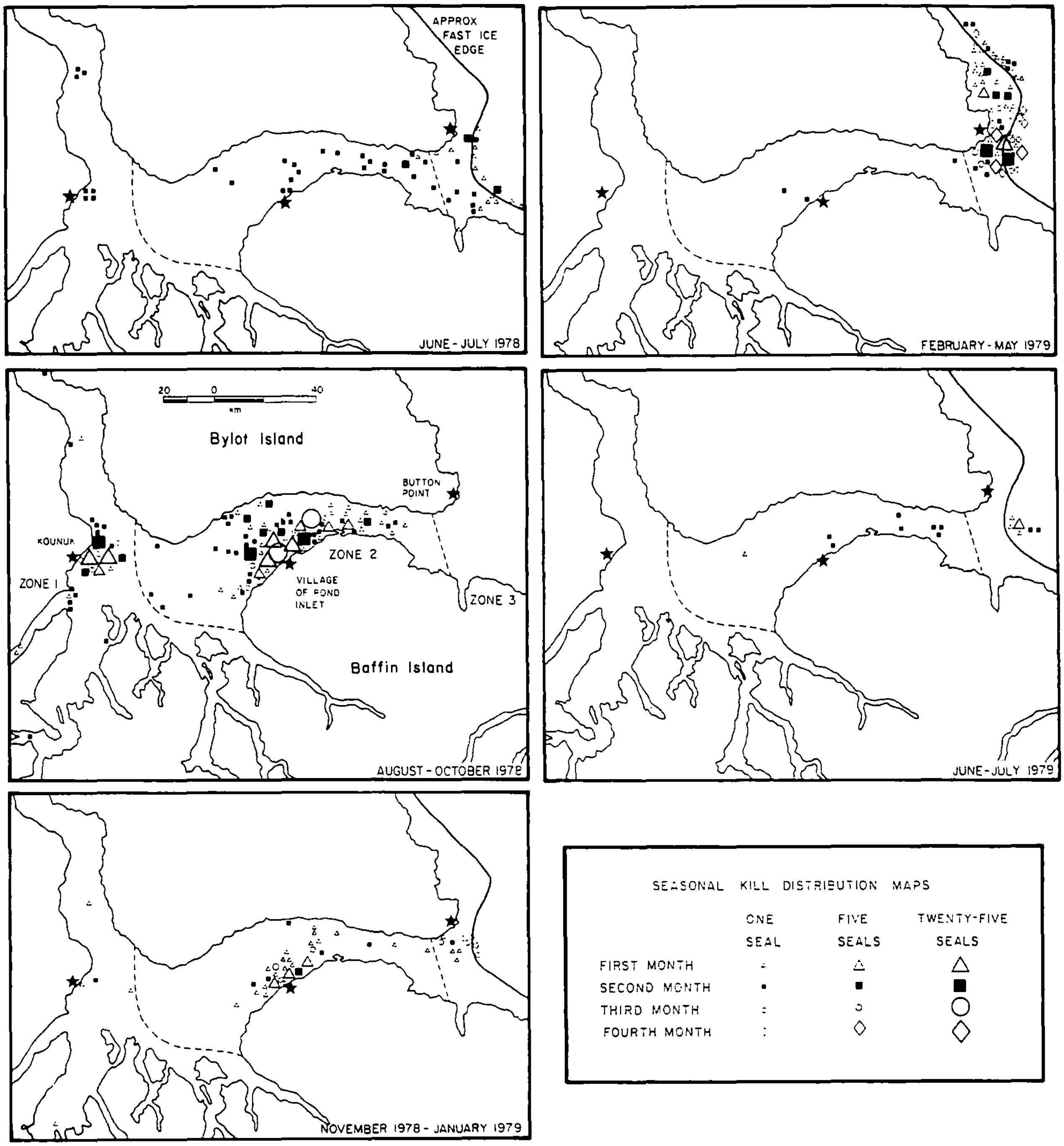


Fig. 34. Patterns of ringed seal harvest in Pond Inlet, 1978-79. Marine waters are divided into three zones: Zone 1 is called 'Pond Inlet--Kounuk' herein; Zone 2 is called 'Pond Inlet--village'; and Zone 3 is called 'Pond Inlet--ice edge'.

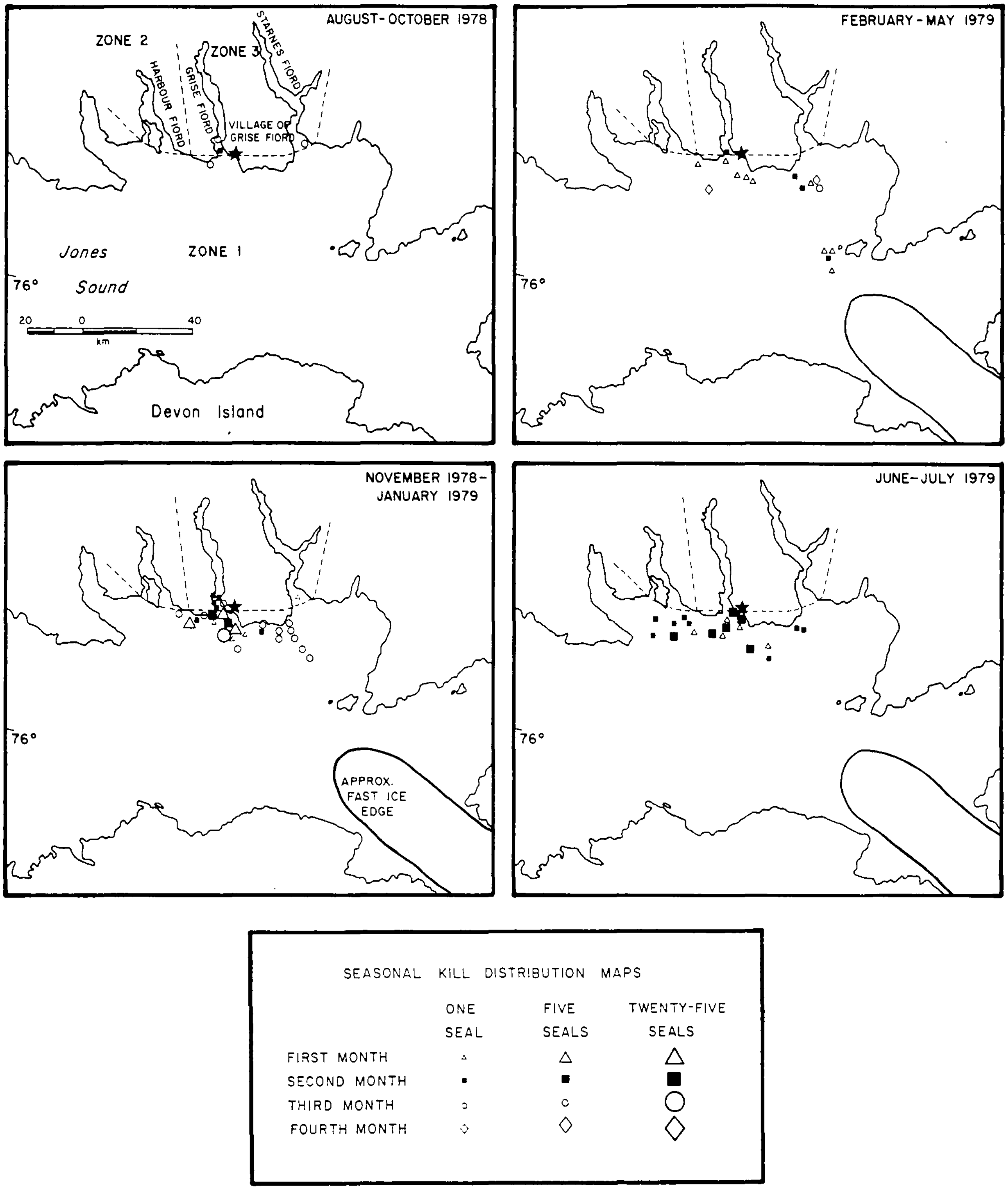


Fig. 35. Patterns of ringed seal harvest near Grise Fiord, 1978-79. Marine waters are divided into three zones, but all samples used in this report are from Zone 1.

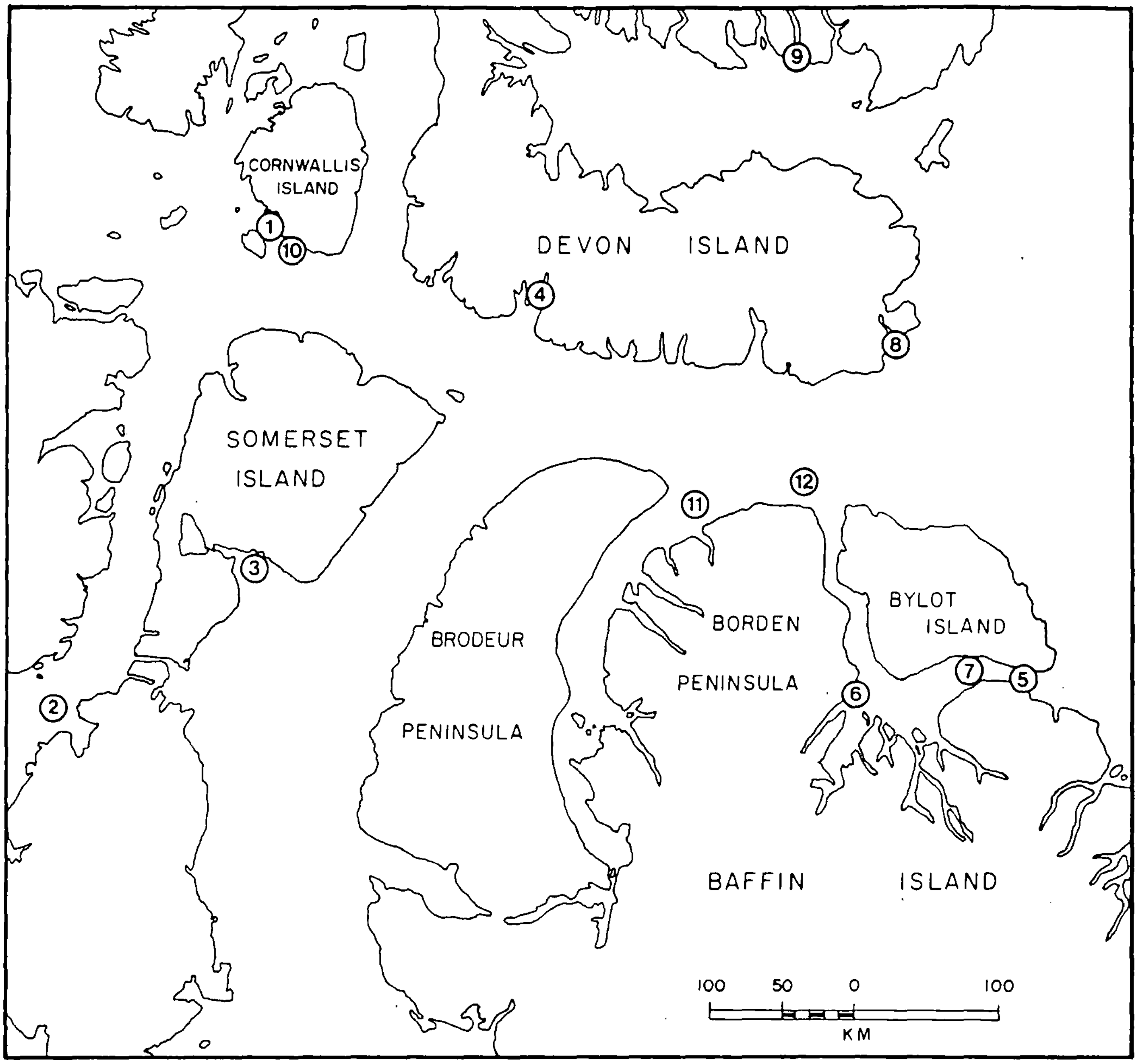


Fig. 36. Observation sites for feeding aggregations of marine mammals and seabirds in the eastern Canadian Arctic, 1976-1983. Numbers refer to locations given in Table 41.

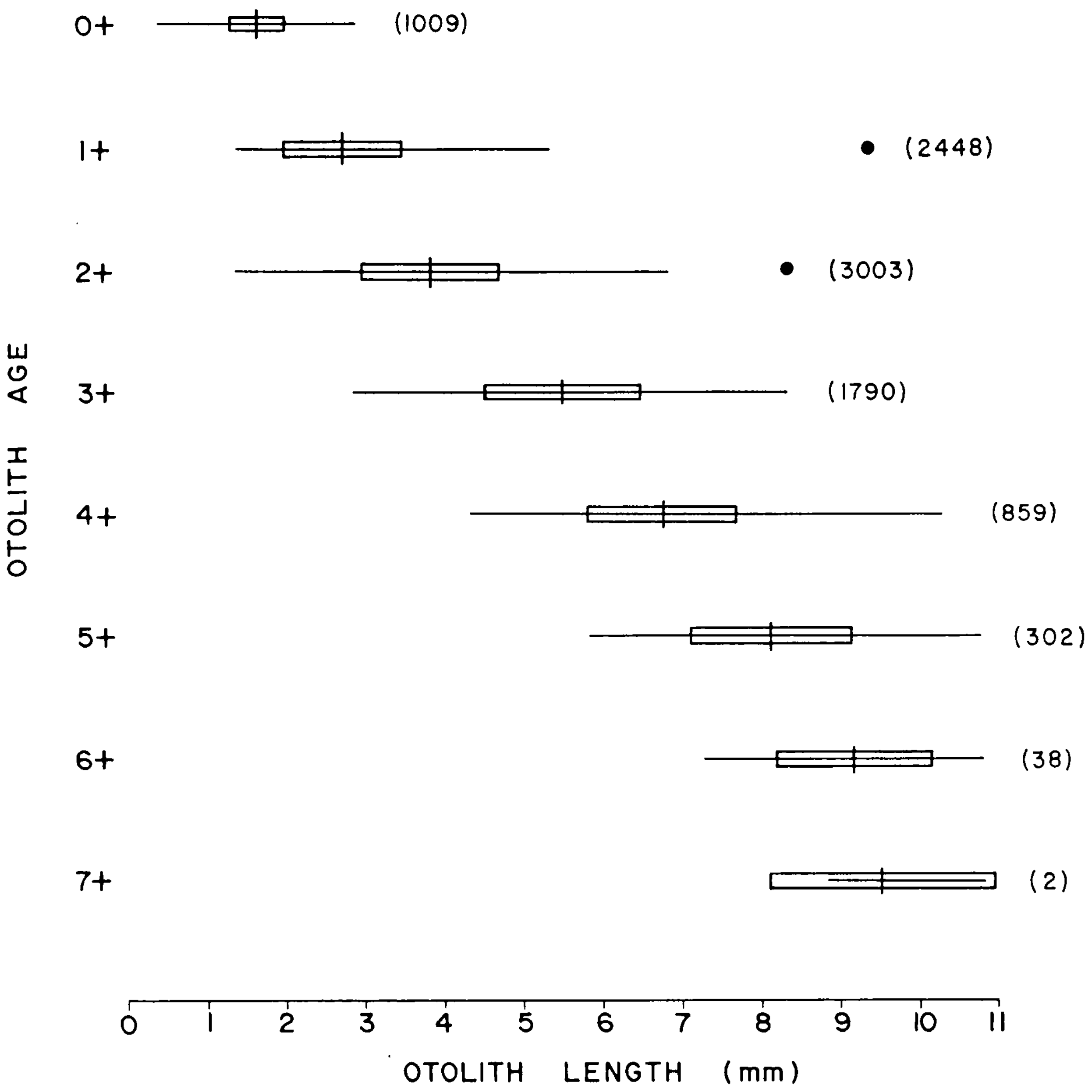
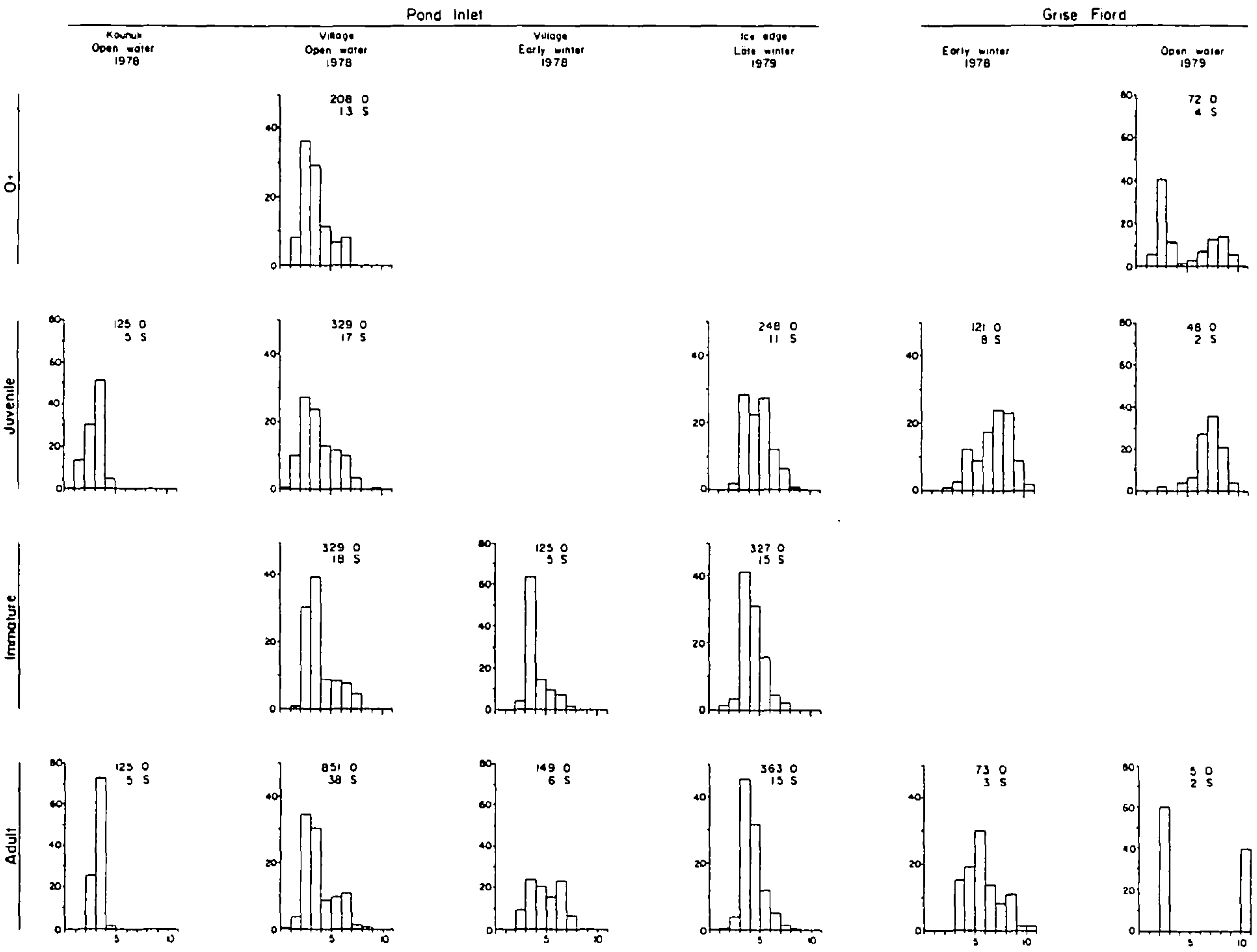


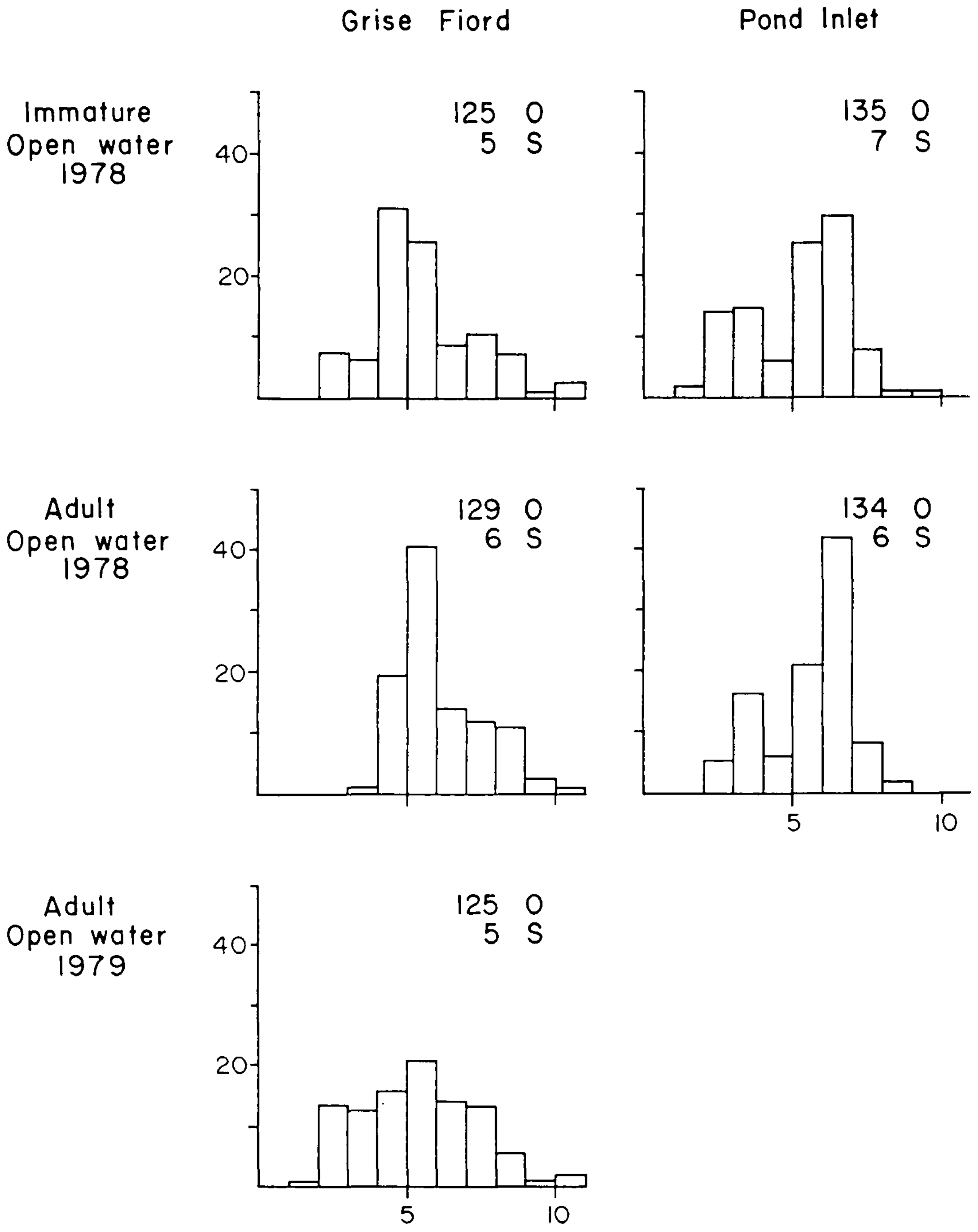
Fig. 37. Lengths of 9451 Arctic cod otoliths in eight age classes. Vertical line = mean, horizontal bar = standard deviation, horizontal line = range. Sample sizes are in parentheses. For age 1+ and age 2+ otoliths, extreme otolith length values (probable errors) are indicated by single dots.



Mean Otolith Lengths (mm) ± sd

O+	–	3.5 ± 1.4	–	–	–	4.9 ± 2.7
Juvenile	3.0 ± 0.7	3.9 ± 1.7	–	5.0 ± 1.3	7.1 ± 1.7	7.2 ± 1.3
Immature	–	3.9 ± 1.5	4.1 ± 1.1	4.4 ± 1.0	–	–
Adult	3.3 ± 0.4	3.8 ± 1.5	5.0 ± 1.5	4.3 ± 1.0	5.9 ± 1.6	5.6 ± 4.1

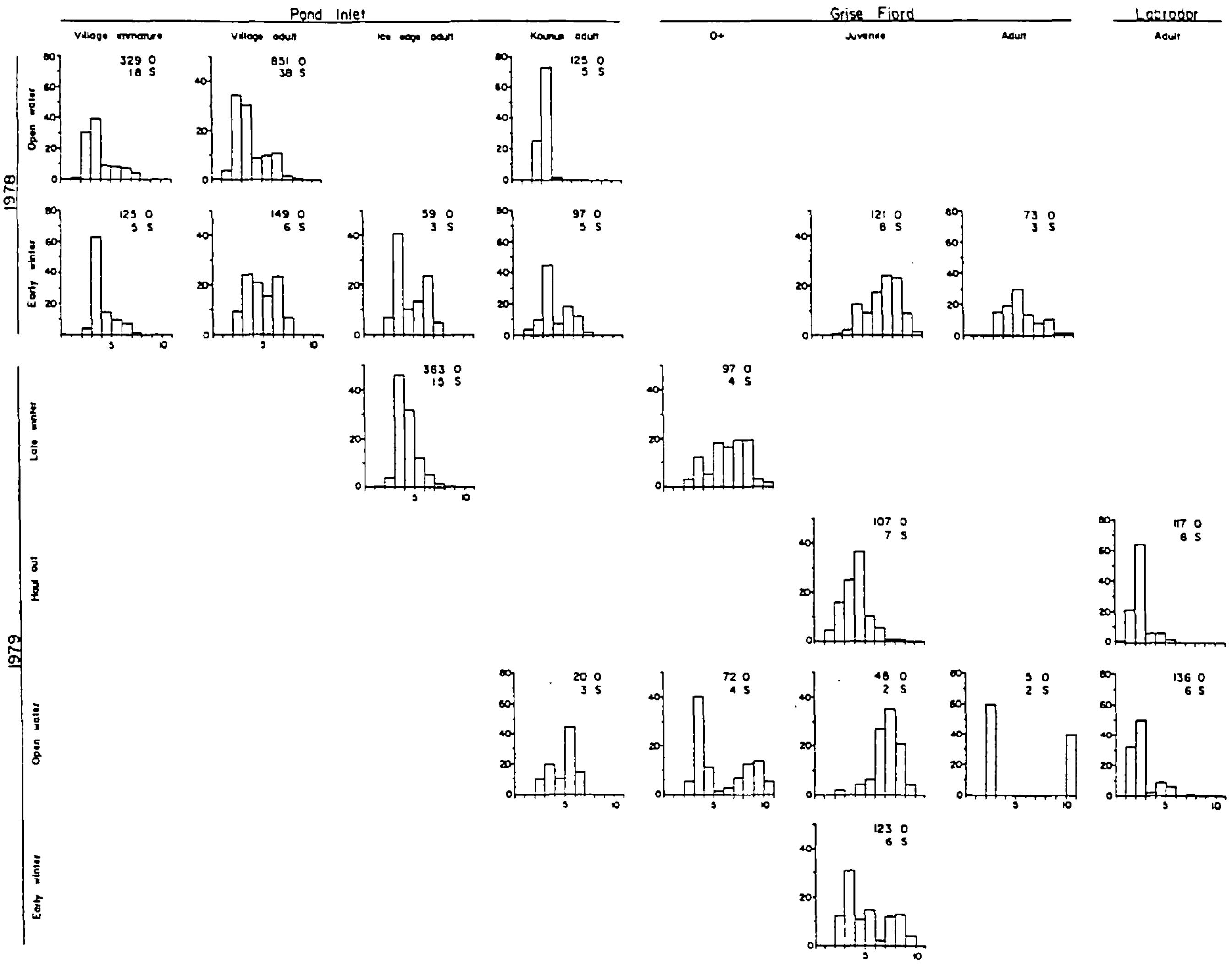
Fig. 38. Length-frequency distributions of Arctic cod otoliths in 0+, juvenile, immature, and adult ringed seal samples taken at various locations and in various seasons. O = number of otoliths, S = number of samples. Abscissa is otolith length (mm); ordinate is percent of number of otoliths.



Mean Otolith Lengths (mm) ± s.d.

Immature	1978	5.5 ± 1.8	5.2 ± 1.7
Adult	1978	6.1 ± 1.4	5.6 ± 1.4
Adult	1979	5.4 ± 1.9	—

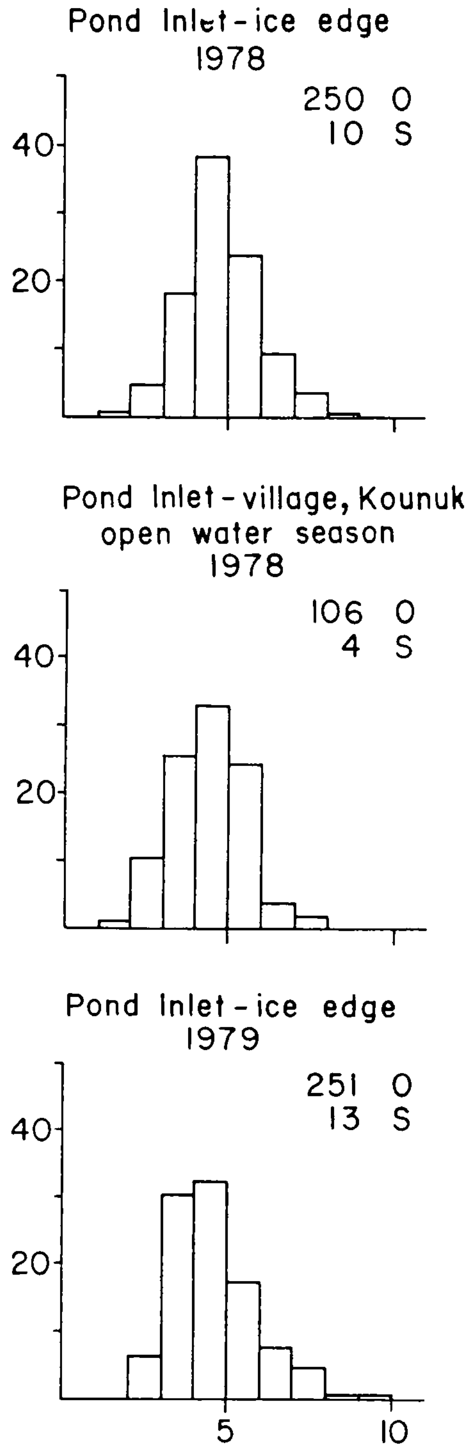
Fig. 39. Length-frequency distributions of Arctic cod otoliths found in harp seal samples taken during the open-water season. O = number of otoliths, S = number of samples. Abscissa is otolith length (mm); ordinate is percent of number of otoliths.



Mean Otolith Lengths (mm) ± s.d.

	Village immature	Village adult	Ice edge adult	Kounuk adult	0+	Juvenile	Adult	Adult
1978								
Open water	3.9 ± 1.5	3.8 ± 1.5	—	3.3 ± 0.4	—	—	—	—
Early winter	4.1 ± 1.1	5.0 ± 1.5	4.8 ± 1.5	4.2 ± 1.4	—	7.1 ± 1.7	5.9 ± 1.6	—
1979								
Late winter	—	—	4.3 ± 1.0	—	6.6 ± 1.8	—	—	—
Haul out	—	—	—	—	—	4.1 ± 1.3	—	2.5 ± 0.8
Open water	—	—	—	4.8 ± 1.2	4.9 ± 2.7	7.2 ± 1.3	5.6 ± 4.1	2.7 ± 1.3
Early winter	—	—	—	—	—	5.3 ± 2.2	—	—

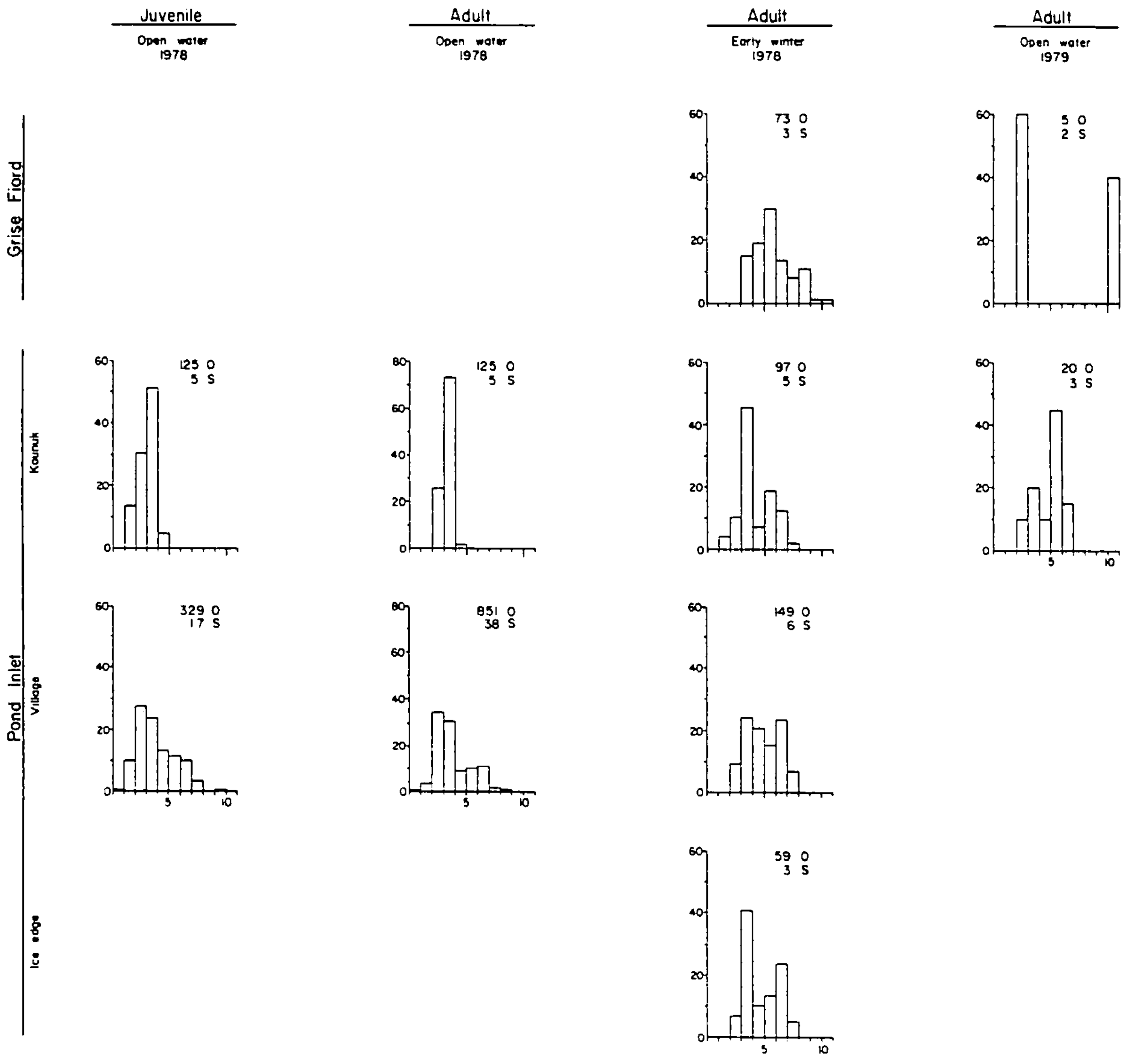
Fig. 40. Length-frequency distributions of Arctic cod otoliths found in samples taken from ringed seals of the same age and collection location but different seasons and years. O = number of otoliths, S = number of samples. Abscissa is otolith length (mm); ordinate is percent of number of otoliths.



Mean Otolith Lengths (mm) ± s.d.

Ice edge 1978	4.8 ± 1.2
Village, Kounuk 1978	4.4 ± 1.1
Ice edge 1979	4.6 ± 1.2

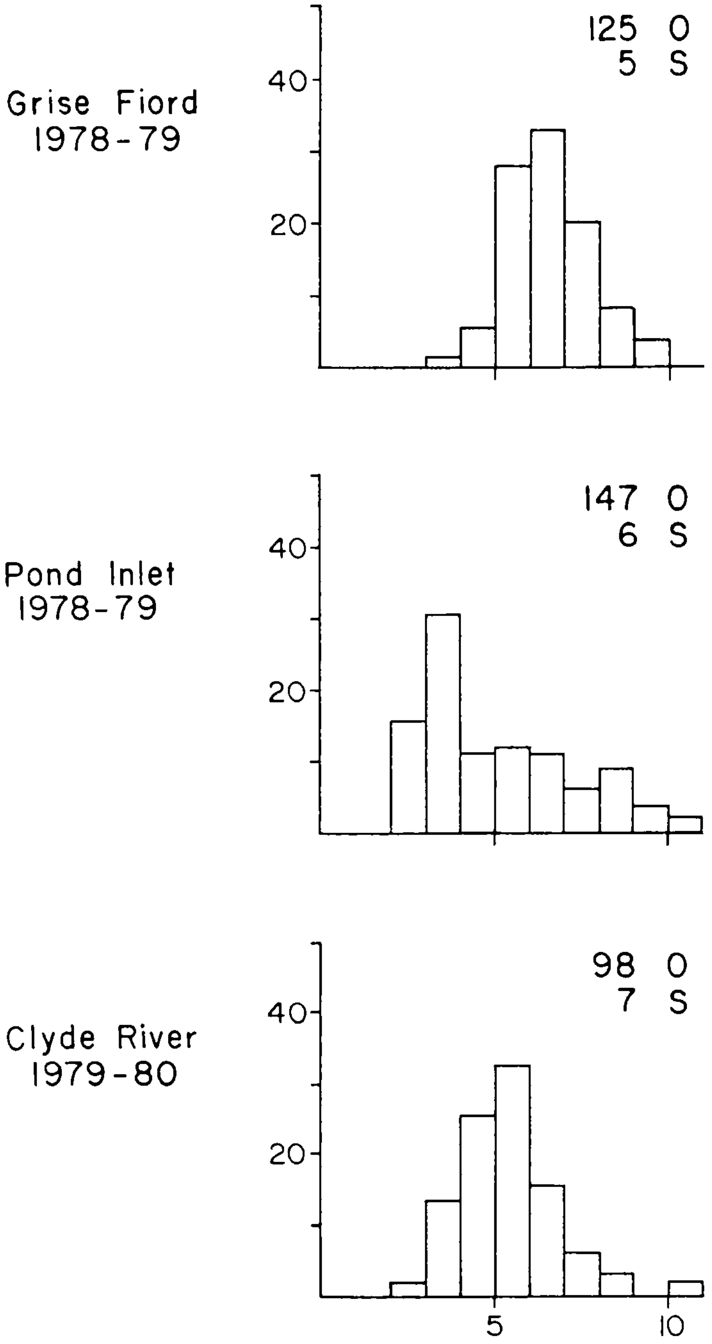
Fig. 41. Length-frequency distributions of Arctic cod otoliths found in narwhal and white whale samples taken at Pond Inlet. O = number of otoliths, S = number of samples. Abscissa is otolith length (mm); ordinate is percent of number of otoliths.



Mean Otolith Lengths (mm) ± s.d.

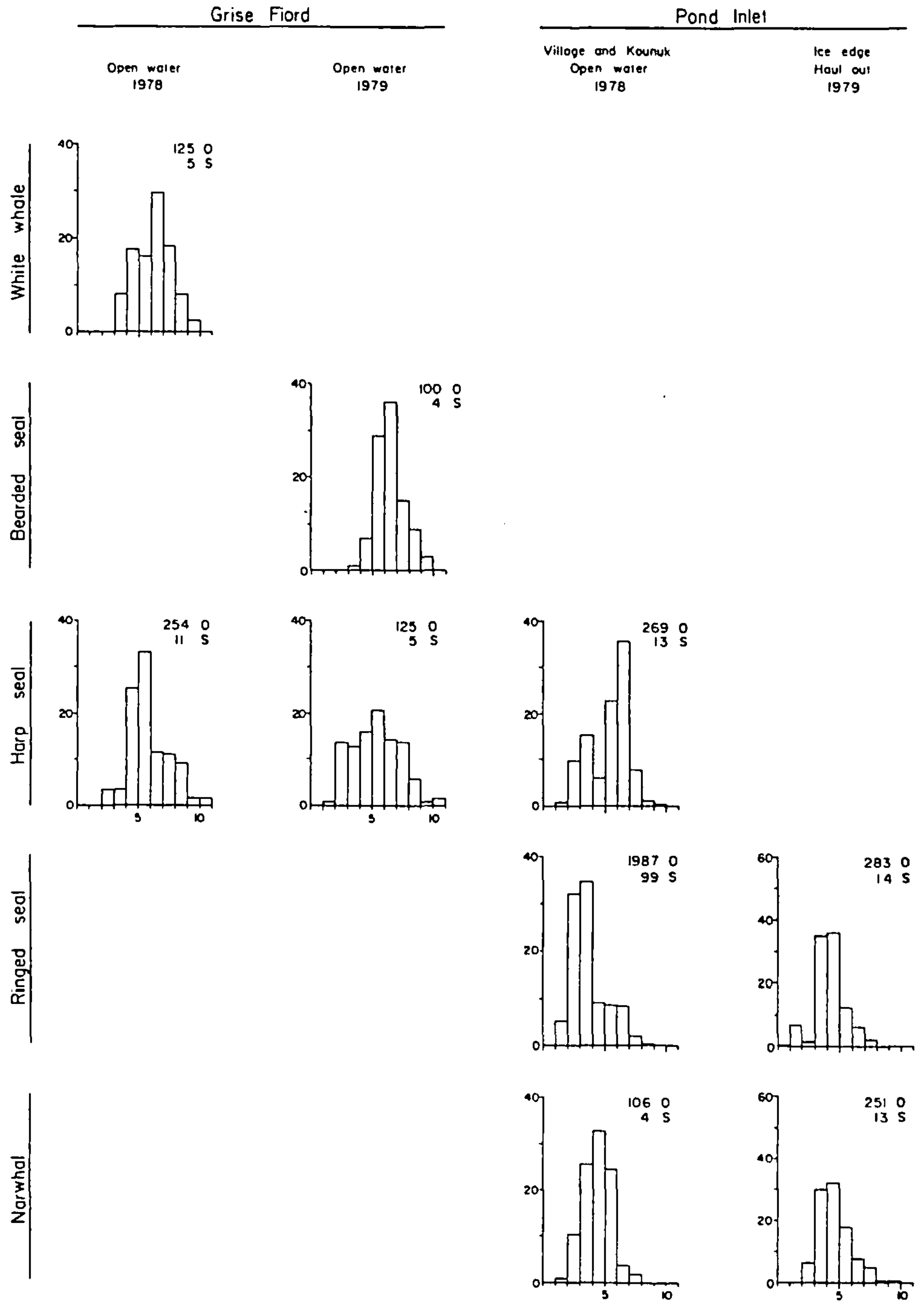
Grise Fiord	—	—	5.9 ± 1.6	5.6 ± 4.1
Pond Inlet				
Kounuk	3.0 ± 0.7	3.3 ± 0.4	4.2 ± 1.4	4.8 ± 1.2
Village	3.9 ± 1.7	3.8 ± 1.5	5.0 ± 1.5	—
Ice edge	—	—	4.8 ± 1.5	—

Fig. 42. Length-frequency distributions of Arctic cod otoliths found in ringed seals collected in different areas. O = number of otoliths, S = number of samples. Abscissa is otolith length (mm); ordinate is percent of number of otoliths.



Mean Otolith Lengths (mm) ± s.d.	
Grise Fiord	6.6 ± 1.2
Pond Inlet	5.1 ± 2.2
Clyde River	5.4 ± 1.5

Fig. 43. Length-frequency distributions of Arctic cod otoliths found in bearded seal samples taken during the open-water season. O = number of otoliths, S = number of samples. Abscissa is otolith length (mm); ordinate is percent of number of otoliths.



Mean Otolith Lengths (mm) ± s.d.

WW	6.2 ± 1.5	—	—	—
BS	—	7.0 ± 1.2	—	—
HS	5.8 ± 1.6	5.4 ± 1.9	5.4 ± 1.6	—
RS	—	—	3.7 ± 1.4	4.2 ± 1.2
NA	—	—	4.4 ± 1.1	4.6 ± 1.2

Fig. 44. Length-frequency distributions of Arcic cod otoliths found in samples of different marine mammal predators collected at the same place and time. O = number of otoliths, S = number of samples. Abscissa is otolith length (mm); ordinate is percent of number of otoliths.

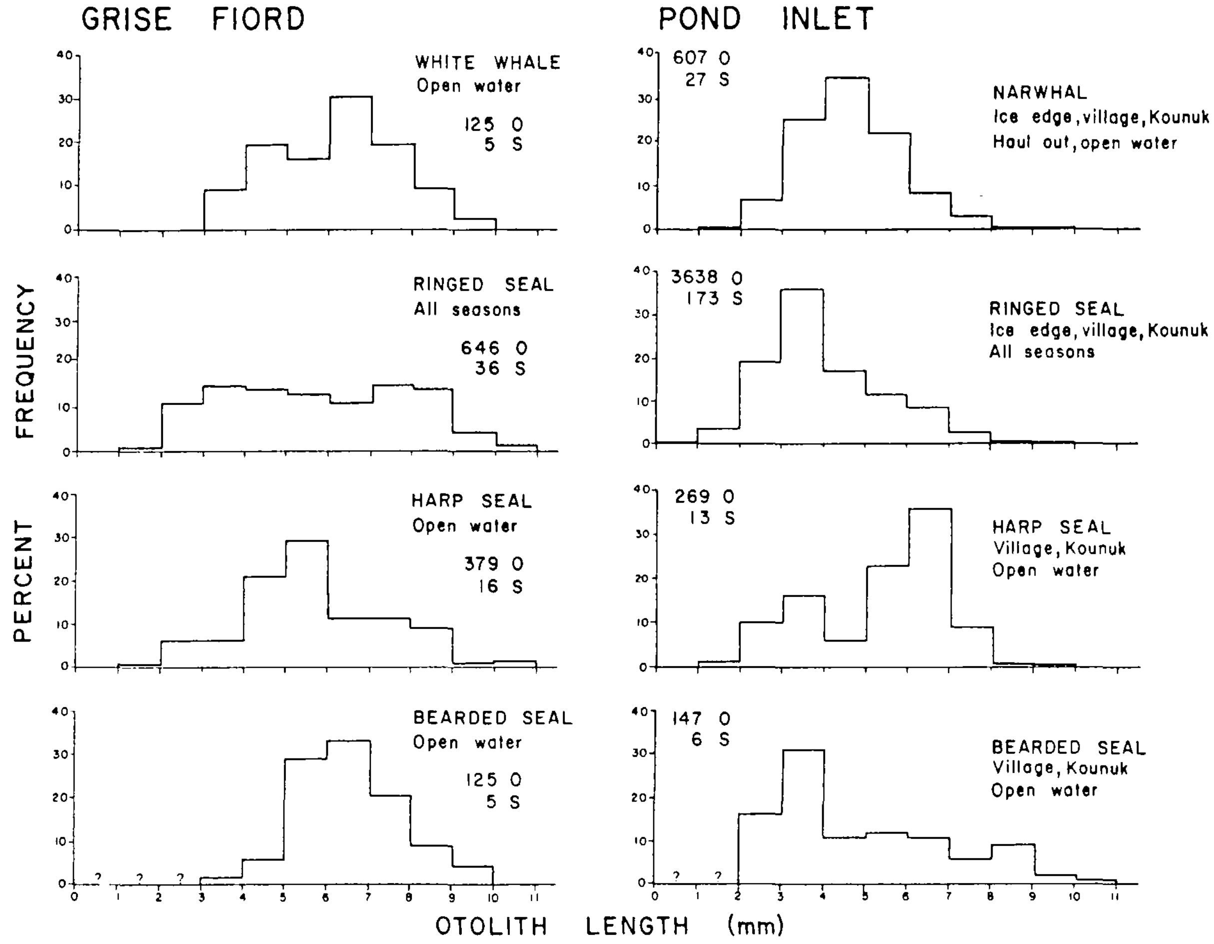


Fig. 45. Length-frequency distributions of Arctic cod otoliths found in samples of marine mammals collected at Grise Fiord and Pond Inlet, 1978-79. O=number of otoliths, S=number of samples. In bearded seal samples <4% of small fish otoliths were not identified to species. It is possible that very small numbers of such otoliths represented Arctic cod. This has been indicated by '?'.

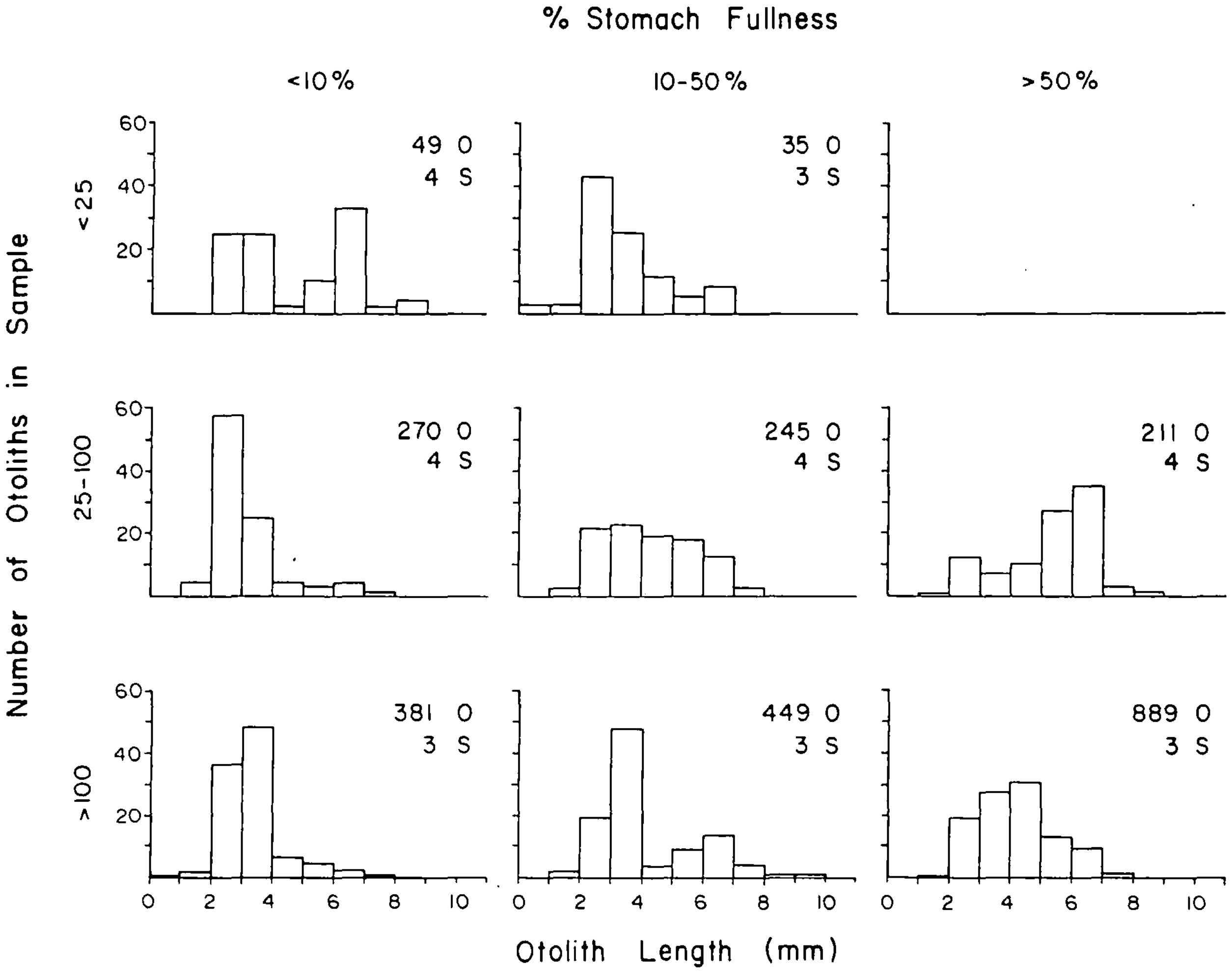


Fig. 46. Length-frequency distributions of Arctic cod otoliths found in ringed seal samples collected near the village of Pond Inlet during the open-water season, 1978. Samples are organized by % stomach fullness (estimated visually when the stomach was examined in the field) and by number of otoliths in the sample. All otoliths in the 28 samples were used. O = number of otoliths, S = number of samples.

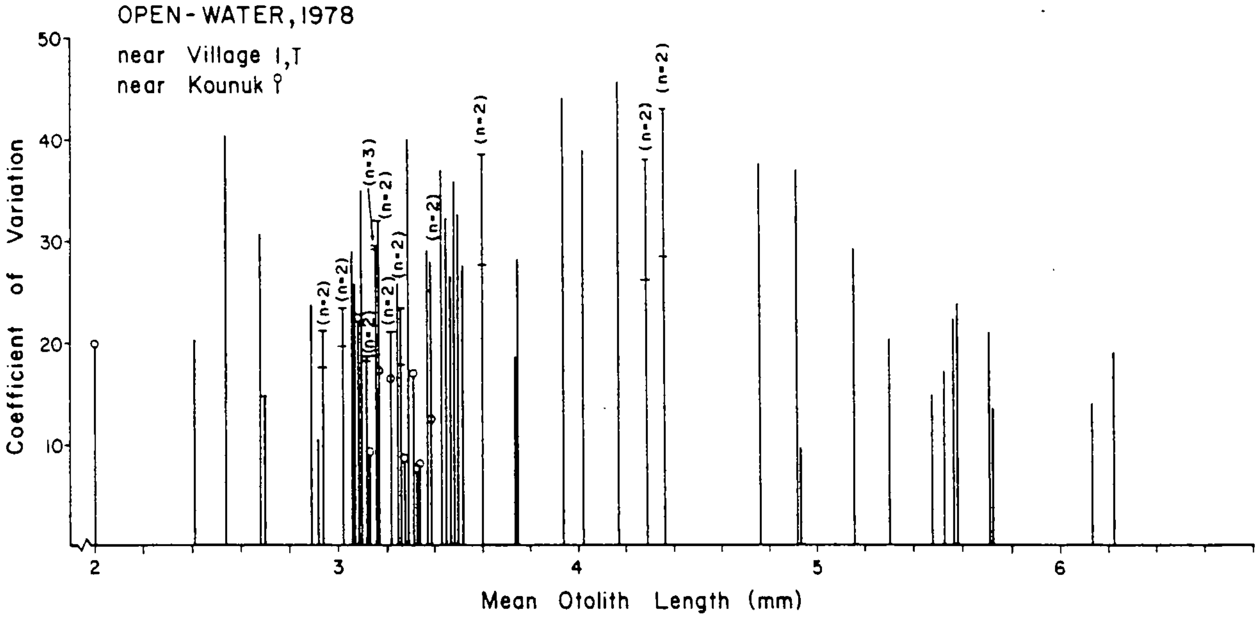


Fig. 47. Coefficients of variation of otolith lengths plotted against mean otolith length in a sample. All samples are from ringed seals and 25 otoliths from each stomach were used in calculating the mean lengths and coefficients. The ringed seals were collected at Pond Inlet during the open-water period in 1978.

LIST OF APPENDICES

APPENDIX 1: DIET OF Y-O-Y ARCTIC COD IN SEVEN REGIONS

The tables in this appendix are organized by sampling region:

Labrador Sea
Northwest Baffin Bay
Lancaster Sound
Brentford Bay
Wellington Channel
Southeastern Beaufort Sea

For each region there are two tables, one providing the mean percent composition of the food items found in Arctic cod stomachs from the various sampling stations, and a second providing the mean percent composition of measured food items by sampling station. Locations of sampling stations are given in the source documents. In all the tables a - means that none of a particular food item was found at a given station. If an entire line of - 's appears on a table it means that the particular food item did not occur in the stomach contents of Arctic cod in that region. A 'P' in a table signifies that a food item constituted <0.1% of the diet.

Table 1-1. Mean percent composition of stomach contents of young-of-the-year Arctic cod collected at stations in the Labrador Sea, 1979 by Buchanan and Foy (1980).

Station	LA-1	LA-2	LA-3	LA-4	LA-5	LA-1A	LD-1	LD-2	LD-3	LF-1	LF-2	LF-3	LF-4	LG-1	LG-2	OB-1	VB-1	LD-2	LD-3	
Date	16/7	17/7	17/7	17/7	17/7	16/7	23/7	24/7	24/7	6/8	6/8	6/8	6/8	7/8	7/8	8/8	29/8	6/9	6/9	
Depth of water (m)	48	108	90	128	90	50	46	62	62	47	123	75	110	95	87	83	87	89	89	Overall
Number of stomachs	6	20	3	4	5	7	20	20	20	20	1	2	5	20	4	20	20	2	8	mean
Mean length (mm)	15.8	18.1	16.5	16.9	17.1	14.1	17.5	18.9	19.6	18.9	18.5	19.6	21.9	16.9	15.9	18.3	29.3	39.2	33.5	20.3
ZOOPLANKTON																				
Copepods																				
Euchaeta glacialis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Calanus finmarchicus	-	3.6	-	3.1	1.6	11.7	3.3	3.8	12.8	7.5	1.4	4.2	0.5	7.0	-	0.6	-	2.9	5.7	3.7
Calanus glacialis	2.5	1.3	-	0.4	0.2	5.9	7.0	13.0	17.3	28.8	1.4	0.6	0.1	5.9	-	2.4	0.4	1.3	1.3	4.7
Calanus hyperboreus	-	-	-	-	-	-	0.6	-	0.1	0.3	-	-	-	-	-	1.2	-	-	-	0.1
Pseudocalanus minutus	-	-	4.0	3.1	0.8	1.4	3.3	12.2	5.7	17.2	-	0.4	0.2	4.3	2.2	26.9	18.8	5.4	10.9	6.2
Limnocalanus macrurus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Acartia longiremis	-	0.2	-	-	-	1.4	-	0.1	0.1	0.6	-	-	0.3	1.5	2.2	0.3	-	0.2	0.2	0.4
Derjuginia tolli	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Eurytemora sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Microcalanus sp.	-	-	-	-	-	-	-	0.4	0.1	-	2.0	-	-	-	-	-	0.9	-	0.2	0.2
Oithona similis	12.7	5.5	24.0	9.8	10.4	8.9	16.2	7.1	6.2	3.0	14.9	9.9	14.5	4.0	15.6	8.2	1.3	18.0	30.4	11.6
Oithona atlantica	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.1	P
Oncaea borealis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.5	0.4	0.2	0.6	0
Unid. Calanoid copepods	11.8	77.9	24.0	19.5	25.5	51.5	17.9	38.2	22.3	24.1	33.8	33.3	40.4	42.6	32.6	15.8	47.5	7.8	11.4	30.4
Unid. Cyclopoid copepods	72.6	8.8	48.0	62.5	61.5	17.6	49.6	23.1	35.3	13.4	44.6	51.7	44.4	33.0	47.4	4.7	-	21.4	24.8	35.0
Unid. Harpacticoid copepods	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Copepod parts	-	2.2	-	-	-	1.4	1.5	-	-	4.3	-	-	-	-	-	1.8	1.3	36.4	12.0	3.2
(Total copepods)	(99.6)	(99.4)	(100)	(100)	(100)	(100)	(99.3)	(97.8)	(99.7)	(99.7)	(98)	(100)	(100)	(97.6)	(100)	(64.9)	(71.4)	(93.9)	(97.3)	95.7
Amphipods	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.4	0.1	P
Euphausiids	0.4	-	-	-	-	-	0.2	0.3	0.1	0.1	-	-	-	0.7	-	0.3	0.9	-	0.1	0.2
Larvacea	-	0.6	-	-	-	-	0.4	1.7	0.2	0.1	2.0	-	-	0.8	-	2.3	2.0	5.2	1.8	0.9
Cirripede	-	-	-	-	-	-	-	-	-	0.1	-	-	-	-	-	0.3	24.9	-	-	1.3
Pteropods	-	-	-	-	-	-	0.1	0.1	-	-	-	-	-	0.1	-	0.6	-	-	0.3	P
Bivalve veliger	-	-	-	-	-	-	-	0.1	-	-	-	-	-	-	-	-	-	0.5	0.4	0.1
Polychaete larva	-	-	-	-	-	-	0.1	-	-	-	-	-	-	-	-	1.8	0.4	-	-	0.1
Chaetognaths	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.6	-	-	-	P
Unidentified eggs	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	29.2	0.4	-	-	1.6
PHYTOPLANKTON																				
Coscinodiscus	-	-	-	-	-	-	-	-	-	-	-	-	-	0.8	-	-	-	-	-	P

Table 1-2. Mean percent composition of measured groups and/or species constituting >5% of the diet of young-of-the-year Arctic cod collected in the Labrador Sea, by Bradstreet and Foy (1980).

Station Date Prey item	Prey size (mm)	LA-1 16/7	LA-2 17/7	LA-3 17/7	LA-4 17/7	LA-5 17/7	LA-1A 16/7	LD-1 23/7	LD-2 24/7	LD-3 24/7	LD-2 6/9	LD-3 6/9	LF-1 6/8	LF-2 6/8	LF-3 6/8	LF-4 6/8	LG-1 7/8	LG-2 7/8	OB-1 8/8	VB-1 29/8	Overall mean
Calanus finmarchicus I	0-1	-	1.3	-	2.0	1.4	10.3	0.9	2.3	8.4	0.5	0.4	2.3	1.4	3.3	0.4	2.1	-	-	-	1.9
II	0-1	-	1.6	-	0.8	0.2	1.4	1.5	1.1	3.9	0.9	0.5	3.5	-	0.9	0.1	4.0	-	0.3	-	1.1
III	0-1	-	0.6	-	0.4	-	-	0.9	0.3	0.4	1.4	2.4	1.7	-	-	-	0.8	-	0.3	-	0.5
IV	1-2	-	-	-	-	-	-	-	0.1	0.1	-	2.3	0.1	-	-	-	0.2	-	-	-	0.1
male	2-3	-	0.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	P
female	2-3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Calanus glacialis I	0-1	1.6	0.9	-	0.4	0.2	4.4	3.9	9.1	12.0	0.2	0.1	12.3	1.4	0.6	-	2.6	-	0.3	-	2.6
II	1	0.8	0.2	-	-	-	1.4	2.9	3.7	5.0	0.4	0.2	13.2	-	-	0.1	2.7	-	0.6	-	1.6
III	2	-	0.2	-	-	-	-	0.1	0.2	0.2	0.7	0.7	3.0	-	-	-	0.6	-	1.5	-	0.4
IV	2-3	-	-	-	-	-	-	-	-	-	0.4	0.1	0.3	-	-	-	-	-	-	-	P
V	3-4	-	-	-	-	-	-	-	-	-	0.2	0.1	-	-	-	-	-	-	-	-	P
Pseudocalanus minutus I/II	0.25	-	-	4.0	3.1	0.8	1.4	1.3	9.7	4.7	3.2	3.1	11.2	-	0.4	0.2	2.6	2.2	8.8	2.4	3.1
III/IV	1	-	-	-	-	-	-	1.2	1.8	0.8	1.8	5.4	4.9	-	-	-	0.9	-	12.0	7.1	1.9
V	1-2	-	-	-	-	-	-	0.1	-	-	-	1.6	-	-	-	-	-	-	4.4	5.1	0.6
male	1-2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.2	P
female	1-2.5	-	-	-	-	-	-	0.7	0.7	0.2	0.4	0.8	1.1	-	-	-	0.8	-	1.8	4.0	0.6
Oithona similis male	1	0.2	-	-	1.6	1.0	-	0.7	0.1	0.4	1.3	0.9	0.5	1.4	1.3	1.0	0.2	-	0.3	0.2	0.6
female	1	7.4	0.9	12.0	3.9	3.6	4.4	6.9	2.2	2.3	4.6	4.0	1.4	5.4	3.8	3.7	1.1	5.2	2.6	1.1	4.0
copepodite	0.5	4.9	4.6	12.0	4.3	5.9	4.4	8.7	4.7	3.5	12.1	25.5	1.2	8.1	4.8	10.0	2.7	10.4	5.3	-	7.0
Calanoid copepod naup. L.	>0.4	2.9	11.2	-	0.4	2.1	22.0	1.0	2.6	3.4	0.2	0.1	3.5	3.4	5.8	0.7	3.2	-	-	-	3.3
naup. M.	0.2-0.4	5.7	41.0	-	12.1	15.2	23.6	8.5	22.3	10.9	4.6	9.0	10.3	18.9	24.7	31.0	21.3	24.4	3.5	0.4	15.1
naup. S.	<0.2	3.3	15.4	20.1	7.0	7.5	5.9	2.5	9.1	6.4	1.1	0.1	4.0	10.8	2.8	8.4	9.0	8.2	-	-	6.4
egg	0.16	-	9.7	3.9	-	0.2	-	5.9	4.2	1.5	1.6	2.2	6.4	0.7	-	0.1	9.1	-	12.3	47.0	5.5
Cyclopoid copepod naup. M.	0.2-0.4	2.0	0.2	-	-	-	-	0.4	0.1	0.1	-	-	0.3	0.7	-	0.1	-	2.2	-	-	0.3
naup. S.	<0.2	3.3	2.5	8.0	0.4	1.5	-	1.5	2.2	0.6	-	0.5	0.5	2.0	0.3	2.3	0.8	11.9	0.9	-	2.1
egg	0.08	67.4	6.1	40.0	62.1	60.0	17.6	47.7	20.8	34.6	21.4	24.3	12.6	41.9	51.5	41.9	32.2	33.3	3.8	-	12.6

Table 1-3. Mean percent composition of stomach contents of young-of-the-year Arctic cod collected at stations in northwest Baffin Bay, 1978 by Sekerak et al. (1979).

Subarea	1	1	1	1	2	3	3	
Depth of water (m)	10	17	25	50	10	10	17	Overall
Number of stomachs (86)	32	16	12	3	5	8	10	mean
Mean lenght (mm)	15.7	14.8	17.5	14.3	19.5	18.8	14.8	16.5
ZOOPLANKTON								
Copepods								
Euchaeta glacialis	-	-	-	-	-	-	-	-
Calanus finmarchicus	1.1	0.3	-	1.7	1.1	-	1.8	0.9
Calanus glacialis	3.9	3.7	-	2.5	8.0	3.6	7.9	4.2
Calanus hyperboreus	0.1	1.3	0.3	-	-	-	0.9	0.4
Pseudocalanus minutus	6.5	21.6	13.2	16.8	9.1	9.1	11.4	12.5
Limnocalanus macrurus	-	-	-	-	-	-	-	-
Acartia longiremis	1.2	0.6	0.5	-	6.8	0.6	0.9	1.5
Derjuginia tolli	-	-	-	-	-	-	-	-
Microcalanus sp.	0.5	-	-	-	2.3	-	-	0.4
Eurytemora sp.	-	-	-	-	-	-	-	-
Oithona similis	18.2	21.3	16.6	10.9	20.5	6.1	12.2	15.1
Oithona atlantica	-	-	-	-	-	-	-	-
Oncaea borealis	0.1	0.7	-	-	-	-	-	0.1
Unid. Calanoid copepods	52.3	34.1	34.3	52.1	22.7	60.1	55.3	44.4
Unid. Cyclopoid copepods	9.3	3.9	2.6	0.8	3.4	6.7	8.8	5.1
Unid. Harpacticoid copepods	-	-	-	-	-	-	-	-
Copepod parts	-	9.5	-	-	-	-	-	1.4
(Total copepods)	(93.1)	(97.1)	(67.5)	(84.9)	(73.9)	(86.1)	(99.1)	(86.0)
Amphipods	-	-	-	-	-	-	-	-
Euphausiids	-	-	-	-	-	-	-	-
Larvacea	5.8	1.6	32.2	6.7	22.7	10.9	-	11.4
Cirripede	-	-	-	-	-	-	-	-
Pteropods	0.6	1.3	-	1.7	-	0.6	-	0.6
Bivalve veliger	-	-	0.3	2.5	-	-	-	0.4
Polychaete larva	-	-	-	-	-	-	-	-
Chaetognaths	-	-	-	-	-	-	-	-
PHYTOPLANKTON								
Coscinodiscus	0.5	-	-	4.2	3.4	2.4	0.9	1.6
Peridinium	-	-	-	-	-	-	-	-

Table 1-4. Mean percentage of measured groups and/or species constituting >5% of the diet of young-of-the-year Arctic cod collected in northwest Baffin Bay, 1978 by Sekerak et al. (1979).

Subarea		1	1	1	1	2	3	3	
Water depth (m)		10	17	25	50	10	10	17	
Prey item	Prey size (mm)								Overall mean
Calanus glacialis I	0-1	2.5	2.3	-	2.5	5.7	2.4	0.9	2.3
II	1	0.5	0.7	-	-	2.3	1.2	7.0	1.7
III	2	0.7	0.7	-	-	-	-	-	0.2
IV	2-3	0.2	-	-	-	-	-	-	P
V	3-4	-	-	-	-	-	-	-	-
Pseudocalanus minutus I/II	0.25	3.8	10.8	7.4	16.0	1.1	3.1	7.0	7.0
III/IV	1	2.5	10.5	5.5	0.8	8.0	6.1	4.4	5.4
V	2	-	0.3	0.3	-	-	-	-	0.1
male	1-2	-	-	-	-	-	-	-	-
female	1-2.5	0.2	-	-	-	-	-	-	P
Oithona similis male	1	-	-	-	-	-	-	-	-
female	1	0.1	1.6	0.5	-	2.3	-	-	0.6
copepodite	0.5	18.0	19.7	16.1	10.9	18.2	6.1	11.4	14.3
egg	0.9	-	-	-	-	-	-	0.9	0.1
Calanoid copepod naup. L.	>0.4	4.6	2.9	1.6	2.5	3.4	1.2	9.7	3.7
naup. M.	0.2-0.4	11.3	11.5	16.9	13.4	4.6	5.5	16.7	11.4
naup. S.	<0.2	8.8	6.2	11.9	17.7	8.0	3.1	15.8	10.2
egg	0.16	27.6	13.4	4.0	18.5	6.8	47.9	13.2	18.8
Cyclopoid copepod naup. M.	0.2-0.4	-	-	-	-	-	-	-	-
naup. S.	<0.2	8.8	3.9	2.6	0.8	3.4	6.7	8.8	5.0
egg	0.08	0.6	-	-	-	-	-	-	0.1
Larvacea		5.8	1.6	32.2	6.7	22.7	10.9	-	11.4

Table 1-5. Mean percent composition of stomach contents of young-of-the-year Arctic cod collected at stations in Lancaster Sound, 1976 by Sekerak et al. (1976a).

Station	East-Mid Sound				Mid-Mid Sound	West-Mid Sound	Cape Warrender					Cape Sherard	Navy Board Inlet	Overall mean
Date	22/7	22/7	22/7	22/7	27/7	28/7	24/7	3/8	17/8	27/8	7/9	23/7	26/7	
Depth of water (m)	0	10	50	150	10	10	10	10	10-50	10-150	50	10	10-50	
Number of stomachs	20	20	20	3	20	13	20	20	13	7	20	20	20	
Mean length (mm)	14.1	12.5	14.6	13.5	15.5	44.0	14.5	13.3	19.7	20.6	25.8	10.2	11.2	15.3
ZOOPLANKTON														
Copepods														
Euchaeta glacialis	-	-	-	-	-	-	0.1	-	-	-	-	-	-	P
Calanus finmarchicus	-	-	0.4	-	-	0.4	-	-	-	-	0.3	-	-	0.1
Calanus glacialis	1.4	-	10.6	-	19.0	5.1	5.7	2.2	13.4	5.4	7.0	0.7	-	5.4
Calanus hyperboreus	0.2	-	-	-	1.2	-	0.1	0.4	-	-	2.0	-	-	0.3
Pseudocalanus minutus	0.2	0.2	4.2	2.5	18.7	12.4	7.1	3.9	18.8	33.0	52.5	0.7	-	11.9
Limnocalanus macrurus	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Acartia longiremis	-	-	-	-	0.3	0.4	-	-	-	-	0.1	-	-	0.1
Derjuginia tolli	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Microcalanus sp.	-	-	-	-	-	-	-	-	-	-	0.3	-	-	P
Eurytemora sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Oithona similis	3.8	1.1	9.1	1.3	3.3	0.7	7.4	3.1	3.5	12.6	2.1	1.8	-	3.8
Oithona atlantica	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Oncaea borealis	-	-	0.4	-	0.5	-	1.4	-	-	0.6	0.2	-	-	0.2
Unid. Calanoid copepods	87.3	91.2	62.6	89.9	48.9	70.9	63.6	77.6	14.4	18.6	11.2	85.4	95.7	62.9
Unid. Cyclopoid copepods	6.8	5.5	7.9	6.3	4.3	6.6	10.2	1.5	-	1.2	0.3	11.4	4.0	5.1
Unid. Harpacticoid copepods	-	-	-	-	-	-	0.1	-	-	-	0.1	-	-	P
Copepod parts	-	-	-	-	-	-	-	-	-	-	-	-	-	-
(Total copepods)	(99.7)	(98.0)	(95.1)	(100)	(96.1)	(95.9)	(95.8)	(88.7)	(50.0)	(71.3)	(75.9)	(100)	(99.6)	89.7
Amphipods	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Euphausiids	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Larvacea	0.3	-	-	-	-	-	-	0.2	5.0	28.1	23.6	-	0.4	4.4
Cirripede	-	-	-	-	-	-	-	-	-	-	0.1	-	-	P
Pteropods	-	0.3	-	-	3.9	2.5	3.8	-	0.5	-	-	-	-	0.8
Bivalve veliger	-	1.5	4.9	-	-	0.4	0.4	0.4	-	-	0.3	-	-	0.6
Polychaete larva	-	-	-	-	-	-	-	-	-	-	0.1	-	-	P
Chaetognaths	-	-	-	-	-	0.4	-	-	-	-	0.1	-	-	P
PHYTOPLANKTON														
Coscinodiscus	-	-	-	-	-	0.4	-	10.7	44.5	0.6	-	-	-	4.3
Peridinium	-	0.2	-	-	-	-	-	-	-	-	-	-	-	P

Table 1-6. Mean percentage of measured groups and/or species constituting >5% of the diet of young-of-the-year Arctic cod collected in Lancaster Sound, 1976 by Sekerak et al. (1976a).

Station		East-Mid Sound				Mid-Mid Sound	West-Mid Sound	Cape Warrender					Cape Sherard	Navy Board Inlet	
Date		22/7				27/7	28/7	26/7	3/8	17/8	27/8	7/9	23/7	26/7	
Prey item	Prey size (m)														Overall mean
ZOOPLANKTON															
Calanus glacialis I	0-1	0.6	-	5.3	-	11.1	4.0	4.0	1.7	2.5	1.2	3.4	0.7	-	2.7
II	1	0.5	-	4.9	-	7.1	1.1	0.7	0.2	4.0	2.4	2.2	-	-	1.8
III	2	0.3	-	0.4	-	0.7	-	1.0	0.2	5.0	1.8	1.3	-	-	0.8
IV	2-3	-	-	-	-	-	-	-	-	2.0	-	0.1	-	-	0.2
V	3-4	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pseudocalanus minutus I/II	0.25	0.2	-	3.4	1.3	10.0	0.4	3.4	3.1	5.0	9.0	27.6	0.7	-	4.9
III/IV	1	-	0.2	0.8	-	3.6	-	3.5	0.9	11.9	22.8	23.8	-	-	5.2
V	2	-	-	-	-	-	0.4	0.3	-	2.0	1.2	0.7	-	-	0.4
egg	0.14	-	-	-	-	4.5	11.3	-	-	-	-	-	-	-	1.2
female	1-2.5	-	-	-	1.3	0.7	0.4	-	-	-	-	0.3	-	-	0.2
Oithona similis male	1	-	-	-	-	-	-	-	-	-	1.8	0.1	-	-	0.1
female	1	-	-	0.8	-	-	-	0.6	-	-	1.2	0.2	-	-	0.2
copepodite	0.25	3.8	1.1	8.3	1.3	3.3	0.7	6.8	3.1	3.5	9.6	1.7	1.8	-	35.
Calanoid copepod naup. L.	>0.4	3.0	1.0	3.8	1.3	7.6	3.3	12.8	5.9	1.5	4.2	2.5	7.3	16.6	5.4
naup. M.	0.2-0.4	28.6	14.2	28.7	21.5	31.8	25.1	26.9	31.4	9.4	10.2	7.3	55.3	63.3	27.2
naup. S.	<0.2	12.9	5.7	13.6	3.8	5.4	23.3	13.4	13.3	0.5	4.2	1.4	11.7	15.5	9.6
egg	0.16	42.8	70.4	16.6	63.3	4.2	19.3	10.5	27.0	3.0	-	-	11.0	0.4	20.6
Cyclopoid copepod naup. M.	0.2-0.4	0.5	0.5	-	-	0.9	0.4	6.7	-	-	-	-	0.7	0.4	0.8
naup. S.	<0.2	6.4	4.9	7.9	6.3	3.4	6.2	3.4	1.5	-	1.2	0.3	10.6	3.6	4.3
egg	0.08	-	0.2	-	-	-	-	0.1	-	-	-	-	-	-	P
PHYTOPLANKTON															
Coscinodiscus	0.15	-	-	-	-	-	0.4	-	10.7	44.5	0.6	-	-	-	4.3

Table 1-7. Mean percent composition of stomach contents of young-of-the-year Arctic cod collected in Brentford Bay, 1977 by Thomson et al. (1978).

Date	30/8	1/9	Overall mean
Depth of water	0	0	
Number of stomachs	18	20	
Mean length (mm)	17.6	21.8	19.7
ZOOPLANKTON			
Copepods			
Euchaeta glacialis	-	0.3	0.2
Calanus finmarchicus	-	-	-
Calanus glacialis	30.8	52.3	41.6
Calanus hyperboreus	-	0.9	0.5
Pseudocalanus minutus	5.3	4.0	4.7
Limnocalanus macrurus	-	-	-
Acartia longiremis	29.8	24.7	27.3
Derjuginia tolli	-	-	-
Microcalanus sp.	-	-	-
Eurytemora sp.	-	-	-
Oithona similis	0.8	4.0	2.4
Oithona atlantica	-	-	-
Oncaea borealis	-	0.5	0.3
Unid. Calanoid copepods	30.4	12.4	21.4
Unid. Cyclopoid copepods	2.6	0.8	1.7
Unid. Harpacticoid copepods	-	-	-
Copepod parts	-	-	2.7
(Total copepods)	(99.7)	(99.8)	99.8
Amphipods	-	-	-
Euphausiids	-	-	-
Larvacea	-	-	-
Cirripede	-	-	-
Pteropods	0.3	0.2	0.3
Bivalve veliger	-	-	-
Polychaete larva	-	-	-
Chaetognaths	-	-	-
PHYTOPLANKTON			
Coscinodiscus	-	-	-
Peridinium	-	-	-

Table 1-8. Mean percentage of groups and/or species comprising >5% of the diet of young-of-the-year Arctic cod collected in Brentford Bay, 1977 by Thomson et al. (1978).

Date			30/8	1/9	
Prey item		Prey size (mm)			Overall mean
Calanus glacialis	I	0-1	28.1	23.7	25.9
	II	1	2.4	27.1	14.8
	III	2	0.3	1.3	0.8
	IV	2-3	0.1	0.2	0.2
Pseudocalanus minutus	I/II	0.25	3.3	1.2	2.3
	III/IV	1	1.6	2.4	2.0
	V	2	0.4	0.2	0.3
	female	1-2	-	0.3	0.2
Acartia longiremis	I/II	0.25	24.1	17.0	20.6
	III/IV	1	5.0	7.0	6.0
	V	2	0.3	0.3	0.3
	female	1-2	0.1	0.5	0.3
Calanoid copepod	naup. L.	>0.4	11.1	3.3	7.2
	naup. M.	0.2-0.4	15.3	3.1	9.2
	naup. S.	<0.2	4.1	0.6	2.4

Table 1-9. Mean percent composition of stomach contents of young-of-the-year Arctic cod collected at stations in Wellington Channel, 1976 by Bain et al. (1977).

Station	PG-132	PG-110	PG-129	PG-144	PG-85	PG-137	PG-47	PG-73	PG-203	PG-14	Overall mean
Date	13/6	13/6	14/6	21/6	21/6	14/6	25/6	25/6	25/6	5/7	
Depth of water (m)	10	5	10	15	25	7.5	15	7.5	25	15	
Number of stomachs	11	4	19	3	2	14	2	3	3	1	
Mean length (mm)	7.0	6.6	7.0	11.1	11.5	7.1	8.1	10.5	0.1	14.0	9.2
ZOOPLANKTON											
Copepods											
Euchaeta glacialis	-	-	-	-	-	-	-	-	-	-	-
Calanus finmarchicus	-	-	-	-	-	-	-	-	-	-	-
Calanus glacialis	-	-	-	-	5.7	-	-	-	-	-	0.6
Calanus hyperboreus	-	-	-	-	-	-	-	-	-	-	-
Pseudocalanus minutus	-	-	-	100	3.7	-	-	93.9	-	5.3	20.3
Limnocalanus macrurus	-	-	-	-	-	-	-	-	-	-	-
Acartia longiremis	-	-	-	-	-	-	-	-	-	-	-
Derjuginia tolli	-	-	-	-	-	-	-	-	-	-	-
Eurytemora sp.	-	-	-	-	-	-	-	-	-	-	-
Microcalanus sp.	-	-	-	-	-	-	-	-	-	-	-
Oithona similis	-	-	-	-	5.7	-	-	-	-	10.5	1.6
Oithona atlantica	-	-	-	-	-	-	-	-	-	-	-
Oncaea borealis	-	-	-	-	-	-	-	-	-	-	-
Unid. Calanoid copepods	87.6	77.8	100	-	67.9	90.8	100	6.1	94.1	79.0	70.3
Unid. Cyclopoid copepods	-	22.2	-	-	16.9	9.2	-	-	5.8	-	5.4
Unid. Harpacticoid copepods	-	-	-	-	-	-	-	-	-	-	-
Copepod parts	-	-	-	-	-	-	-	-	-	-	-
(Total copepods)	(87.6)	(100)	(100)	(100)	(100)	(100)	(100)	(100)	(100)	(94.7)	(98.2)
Amphipods	-	-	-	-	-	-	-	-	-	-	-
Euphausiids	-	-	-	-	-	-	-	-	-	-	-
Larvacea	-	-	-	-	-	-	-	-	-	-	-
Cirripede	12.4	-	-	-	-	-	-	-	-	-	1.2
Pteropods	-	-	-	-	-	-	-	-	-	5.3	0.5
Bivalve veliger	-	-	-	-	-	-	-	-	-	-	-
Polychaete larva	-	-	-	-	-	-	-	-	-	-	-
Chaetognaths	-	-	-	-	-	-	-	-	-	-	-
PHYTOPLANKTON											
Coscinodiscus	-	-	-	-	-	-	-	-	-	-	-
Peridinium	-	-	-	-	-	-	-	-	-	-	-

Table 1-10. Mean percentage of measured groups and/or species constituting >5% of the diet of young-of-the-year Arctic cod collected in Wellington Channel, 1976 by Bain et al. (1977).

Station			PG-132	PG-110	PG-129	PG-144	PG-85	PG-137	PG-47	PG-73	PG-203	PG-14	
Date			13/6	13/6	14/6	21/6	21/6	14/6	25/6	25/6	25/6	5/6	
Prey item		Prey size (mm)											Overall mean
Pseudocalanus minutus	female	1-2	-	-	-	6.2	1.9	-	-	3.5	-	5.3	1.7
	eggs	0.14	-	-	-	93.9	1.9	-	-	90.5	-	-	18.6
Oithona similis	copepodite	0.5	-	-	-	-	5.7	-	-	-	-	10.5	1.6
Calanoid copepod	naup. L.	>0.4	-	-	-	-	-	20.4	-	-	11.8	10.5	4.3
	naup. M.	0.2-0.4	12.4	5.6	-	-	15.1	28.2	-	3.5	17.7	36.8	11.9
	naup. S.	<0.2	42.7	33.3	-	-	47.2	31.3	83.3	2.6	58.8	31.6	33.1
	copepodite	0.5	2.5	-	-	-	5.7	-	-	-	-	-	0.8
	egg	0.14-0.16	30.1	38.9	100.0	-	-	10.9	16.7	-	5.8	-	20.2
Cyclopoid copepod	naup. S.	<0.2	-	22.2	-	-	15.1	4.6	-	-	5.8	-	4.8
	naup. M.	0.2-0.4	-	-	-	-	1.9	-	-	-	-	-	0.2
	egg	0.08	-	-	-	-	-	4.6	-	-	-	-	0.5

Table 1-11. Mean percent composition of stomach contents of young-of-the-year Arctic cod collected at stations in the southeastern Beaufort Sea, 1981 by Griffiths and Buchanan (1982).

Station	L-1	N-5	N-6	N-7	N-9	N-10	N-11	N-13	L-1	
Date	1/8	11/8	11/8	11/8	18/8	18/8	18/8	2589	6/9	
Depth of water (m)	15	20	15-20	15	15	5-15	15	10	15	Overall
Number of stomachs	20	9	12	20	16	9	8	2	3	mean
Mean length (mm)	14.2	18.1	17.3	16.4	20.1	21.9	15.5	35.8	20.1	19.9
ZOOPLANKTON										
Copepods										
Euchaeta glacialis	-	-	-	-	-	-	-	-	-	-
Calanus finmarchicus	-	-	-	-	-	-	-	-	-	-
Calanus glacialis	-	0.4	1.9	0.2	2.7	1.7	4.8	1.5	-	1.5
Calanus hyperboreus	-	-	-	-	2.8	1.7	-	6.3	-	1.2
Pseudocalanus minutus	7.6	27.9	70.4	35.5	24.7	4.2	23.5	27.5	12.6	26.0
Limnocalanus macrurus	-	-	-	-	0.1	-	-	0.5	-	0.1
Eurytemora sp.	-	-	-	-	0.1	-	-	-	-	P
Derjuginia tolli	-	-	-	-	-	-	-	1.5	-	0.2
Acartia longiremis	-	-	-	-	-	-	-	-	-	-
Oithona similis	0.2	-	-	-	-	-	-	-	-	P
Oithona atlantica	-	-	-	-	-	-	-	-	-	-
Microcalanus sp.	-	-	-	-	-	-	-	-	-	-
Oncaea borealis	0.4	-	-	-	-	-	-	-	-	P
Unid. Calanoid copepods	91.6	67.7	27.6	64.3	44.9	90.1	69.9	40.1	81.9	64.2
Unid. Cyclopoid copepods	-	-	-	-	0.1	-	0.6	-	5.6	0.7
Unid. Harpacticoid copepods	0.2	-	-	-	-	-	-	-	-	P
Copepod parts	-	4.0	-	-	24.7	2.3	1.2	22.2	-	6.0
(Total copepods)	(100)	(100)	(100)	(100)	(100)	(100)	(100)	(99.5)	(100)	99.9
Amphipods	-	-	-	-	-	-	-	-	-	-
Euphausiids	-	-	-	-	-	-	-	0.5	-	0.1
Larvacea	-	-	-	-	-	-	-	-	-	-
Cirripede	-	-	-	-	-	-	-	-	-	-
Pteropods	-	-	-	-	-	-	-	-	-	-
Bivalve veliger	-	-	-	-	-	-	-	-	-	-
Polychaete larva	-	-	-	-	-	-	-	-	-	-
Chaetognaths	-	-	-	-	-	-	-	-	-	-
PHYTOPLANKTON										
Coscinodiscus	-	-	-	-	-	-	-	-	-	-
Peridinium	-	-	-	-	-	-	-	-	-	-

Table 1-12. Mean percentage of measured groups and/or species constituting >5% of the diet of young-of-the-year Arctic cod collected in the southeastern Beaufort Sea, 1981 by Griffiths and Buchanan (1982).

Station			L-1	N-5	N-6	N-7	N-9	N-10	N-11	N-13	L-1	
Date			1/8	11/8	11/8	11/8	18/8	18/8	18/8	25/8	6/9	
Prey item		Prey size (mm)										Overall mean
Pseudocalanus minutus	I/II	0.25	4.4	9.2	59.6	25.9	9.2	3.3	22.9	4.8	12.6	16.9
	III/IV	0-1	0.2	9.2	8.9	9.3	12.6	0.9	0.6	17.4	-	6.6
	V	1-2	-	0.4	1.0	0.2	0.6	-	-	0.5	-	0.3
	male	1-2	0.2	-	-	-	-	-	-	-	-	P
	female	1-2	2.7	9.2	1.0	0.2	2.3	-	-	4.8	-	2.2
Calanoid copepod	naup. L.	>0.4	-	-	1.0	0.2	0.7	0.5	0.6	0.5	67.9	7.9
	naup. M.	0.2-0.4	24.9	4.8	21.8	42.2	20.6	81.6	62.2	-	14.0	30.2
	naup. S.	<0.2	12.2	0.4	3.9	21.1	2.4	7.9	6.5	-	-	6.0
	egg	0.16	54.4	62.5	1.0	0.9	21.1	0.1	0.6	39.6	-	20.0
Copepod parts			-	4.0	-	-	24.7	2.3	1.2	22.0	-	6.0

APPENDIX 2: AGE-FREQUENCY DISTRIBUTIONS OF ARCTIC COD OTOLITHS FOUND IN VARIOUS PREDATOR SAMPLES

Table 2-1. Age-frequency distribution for Arctic cod otoliths found in narwhal samples.

SAMPLE	AGE			AGE (YEARS)							
NO.	MEAN	SD	NO.	0+	1+	2+	3+	4+	5+	6+	7+
836	2.8	1	25	0	3	6	10	6	0	0	0
838	3.3	1	25	0	1	3	12	6	3	0	0
830	2.5	.9	25	0	4	7	12	2	0	0	0
832	2.6	.9	25	0	1	13	5	6	0	0	0
834	2	.8	25	0	7	11	7	0	0	0	0
835	2.2	.9	25	0	5	12	5	3	0	0	0
837	1.9	.6	25	0	6	15	4	0	0	0	0
845	2.4	.7	25	0	3	10	12	0	0	0	0
846	2.3	.6	25	0	1	16	7	1	0	0	0
850	2.6	1	25	0	3	10	7	5	0	0	0
828	1.8	.9	50	0	22	18	8	2	0	0	0
841	1.7	1.2	3	0	2	0	1	0	0	0	0
842	1	0	3	0	3	0	0	0	0	0	0
844	2.1	.9	50	1	16	13	19	1	0	0	0
802	2.7	.8	25	0	0	12	9	3	1	0	0
803	2.6	.9	25	0	3	8	10	4	0	0	0
804	2.3	1.2	25	0	9	4	8	3	1	0	0
805	2.4	1	25	0	4	10	7	4	0	0	0
806	1.4	.6	25	0	17	7	1	0	0	0	0
807	2.1	.6	8	0	1	5	2	0	0	0	0
809	2	.9	20	0	7	9	2	2	0	0	0
812	1.3	.5	10	0	7	3	0	0	0	0	0
811	1	0	1	0	1	0	0	0	0	0	0
813	1.6	.7	12	0	6	5	1	0	0	0	0
815	2.1	.7	25	0	5	12	8	0	0	0	0
814	2.7	.6	25	0	0	10	13	2	0	0	0
801	3.3	1	25	0	2	2	9	10	2	0	0

Table 2-2. Age-frequency distribution for Arctic cod otoliths found in white whale samples.

SAMPLE NO.	AGE			AGE (YEARS)							
	MEAN	SD	NO.	0+	1+	2+	3+	4+	5+	6+	7+
205	.8	1.1	25	11	12	1	0	0	1	0	0
208	.7	.5	25	7	18	0	0	0	0	0	0
200	.4	.6	25	18	5	2	0	0	0	0	0
207	.2	.4	25	19	6	0	0	0	0	0	0
209	.9	.7	25	7	14	4	0	0	0	0	0
211	3.4	1.1	25	0	0	5	9	7	3	1	0
213	3.3	1.1	25	0	0	7	9	4	5	0	0
212	2.6	1.1	25	0	5	6	10	3	1	0	0
214	2.7	1.3	25	0	5	7	7	3	3	0	0
215	2.8	1.2	25	0	5	3	10	6	1	0	0

Table 2-3. Age-frequency distribution for Arctic cod otoliths found in bearded seal samples.

SAMPLE	AGE			AGE (YEARS)							
NO.	MEAN	SD	NO.	0+	1+	2+	3+	4+	5+	6+	7+
525	2.9	.7	25	0	0	8	12	5	0	0	0
511	3.5	.9	25	0	0	3	10	9	3	0	0
524	3.6	.6	25	0	0	0	12	12	1	0	0
526	3.5	.9	25	0	0	3	10	10	1	1	0
527	3	.7	25	0	0	6	15	3	1	0	0
500	2.3	.7	25	0	3	13	8	1	0	0	0
504	1.7	.8	25	0	13	7	5	0	0	0	0
505	4.2	.8	25	0	0	0	4	14	5	2	0
507	2.8	.8	25	0	1	8	12	4	0	0	0
516	2.6	1.2	22	0	3	10	4	3	2	0	0
502	2.8	1.8	25	1	5	8	3	1	5	2	0
518	2.9	.6	25	0	0	5	17	3	0	0	0
520	3.4	.8	25	0	0	2	14	7	2	0	0
519	2	0	1	0	0	1	0	0	0	0	0
521	2.6	.9	5	0	1	0	4	0	0	0	0
513	2.7	1.1	14	0	2	4	4	4	0	0	0
522	3.2	.7	25	0	0	4	14	6	1	0	0
512	2.3	.6	3	0	0	2	1	0	0	0	0
540	.3	.7	25	21	2	1	1	0	0	0	0
539	1.1	1.1	25	11	3	8	3	0	0	0	0
541	.1	.4	25	24	0	1	0	0	0	0	0
537	1	0	25	0	25	0	0	0	0	0	0
538	.7	.6	25	9	14	2	0	0	0	0	0

Table 2-4. Age-frequency distribution for Arctic cod otoliths found in harp seal samples.

SAMPLE NO.	AGE			AGE (YEARS)							
	MEAN	SD	NO.	0+	1+	2+	3+	4+	5+	6+	7+
23	2.2	1.6	25	0	14	4	1	1	5	0	0
31	2.3	.5	25	0	0	17	8	0	0	0	0
34	2.8	.8	25	0	0	9	13	2	1	0	0
41	4.2	.9	25	0	0	0	6	10	8	1	0
48	2.9	.9	25	0	0	9	12	2	2	0	0
52	4.4	.8	25	0	0	0	3	9	12	1	0
27	2.6	.8	25	0	2	8	14	0	1	0	0
33	2.8	.6	25	0	0	8	15	2	0	0	0
32	5.3	.5	4	0	0	0	0	0	3	1	0
49	2.6	.8	25	0	0	14	7	4	0	0	0
30	2.7	1	25	0	0	14	6	3	2	0	0
60	4.1	1	25	0	0	1	5	12	4	3	0
55	2.9	1	25	0	1	7	12	3	2	0	0
54	1.4	.8	25	1	16	7	0	1	0	0	0
62	3.3	1	25	0	0	6	8	8	3	0	0
57	1.7	.9	25	0	13	8	3	1	0	0	0
12	3.1	.9	25	0	1	4	12	7	1	0	0
4	2	.8	25	0	7	13	4	1	0	0	0
16	3.6	.5	5	0	0	0	2	3	0	0	0
13	3	1.2	5	0	1	0	2	2	0	0	0
9	2	1.2	25	0	14	3	3	5	0	0	0
2	3.7	.7	25	0	0	0	12	9	4	0	0
8	3.5	.8	25	0	0	2	12	8	3	0	0
14	3.8	.4	25	0	0	0	6	19	0	0	0
3	3.5	.6	25	0	0	1	11	13	0	0	0
7	4.2	1.1	25	0	0	2	4	8	9	2	0
5	3.2	.6	25	0	0	2	15	8	0	0	0
15	2	.7	9	0	2	5	2	0	0	0	0
6	1.6	.7	25	0	13	10	2	0	0	0	0

Table 2-5. Age-frequency distribution for Arctic cod otoliths found in ringed seal samples.

SAMPLE NO.	AGE			AGE (YEARS)							
	MEAN	SD	NO.	0+	1+	2+	3+	4+	5+	6+	7+
1764	1	.3	25	1	23	1	0	0	0	0	0
1776	.6	1	25	17	3	3	2	0	0	0	0
1786	.3	.7	16	14	0	2	0	0	0	0	0
1784	.8	.6	25	7	15	3	0	0	0	0	0
1812	.6	.5	25	10	15	0	0	0	0	0	0
1787	1	0	1	0	1	0	0	0	0	0	0
1767	.1	.3	25	22	3	0	0	0	0	0	0
1800	2	1.1	25	2	5	11	5	1	1	0	0
1791	.7	.5	23	8	15	0	0	0	0	0	0
1808	.6	.5	25	11	14	0	0	0	0	0	0
1821	.2	.4	13	10	3	0	0	0	0	0	0
1789	.8	.9	25	10	12	1	2	0	0	0	0
1851	.2	.7	25	22	0	3	0	0	0	0	0
1852	.1	.4	25	23	1	1	0	0	0	0	0
1853	0	0	18	18	0	0	0	0	0	0	0
1854	2.5	.7	2	0	0	1	1	0	0	0	0
1856	1.2	.9	25	5	11	7	2	0	0	0	0
1857	1.2	1.1	25	9	6	6	4	0	0	0	0
1859	3	0	1	0	0	0	1	0	0	0	0
1743	5	0	1	0	0	0	0	0	1	0	0
1735	2.6	2	21	0	11	3	0	0	5	2	0
1750	4	1.1	25	0	0	3	5	8	8	1	0
1737	1.5	.6	25	1	11	13	0	0	0	0	0
1712	4	1.1	22	0	0	3	4	6	9	0	0
1711	3.4	.7	25	0	0	2	11	11	1	0	0
1716	3.3	1.1	25	0	1	5	8	7	4	0	0
1718	3.1	1.8	25	0	7	5	2	1	10	0	0
1516	3.5	.7	2	0	0	0	1	1	0	0	0
1520	3	1.9	6	0	2	1	0	1	2	0	0
1519	3.9	1.1	21	0	0	3	5	4	9	0	0
1506	4	0	1	0	0	0	0	1	0	0	0
1508	3	1.3	25	0	2	8	9	2	3	1	0
1513	3.9	1.2	16	0	0	2	4	5	3	2	0
1511	3.7	1.2	25	0	0	5	6	7	5	2	0
1510	4.6	.9	25	0	0	0	3	7	12	3	0
1732	1.3	1.5	3	1	1	0	1	0	0	0	0
1724	2.5	.6	4	0	0	2	2	0	0	0	0
1731	2.6	1	7	0	1	2	3	1	0	0	0
1723	1	.9	18	4	12	1	0	1	0	0	0
1725	2.6	.7	25	0	0	13	10	2	0	0	0

Continued...

Table 2-5. Continued.

SAMPLE NO.	AGE			AGE (YEARS)							
	MEAN	SD	NO.	0+	1+	2+	3+	4+	5+	6+	7+
1727	1.2	.5	25	1	17	7	0	0	0	0	0
1729	2	.5	25	0	4	18	3	0	0	0	0
1744	4.4	.6	19	0	0	0	1	9	9	0	0
1740	3.5	.9	29	0	1	2	12	10	4	0	0
1707	3	1.4	5	0	0	3	0	1	1	0	0
1702	4.1	1	18	0	0	1	5	4	8	0	0
1701	2.7	1	25	0	1	11	10	0	3	0	0
1706	4	1.2	25	0	1	1	8	3	12	0	0
1705	2.1	.8	25	0	3	19	2	0	1	0	0
1708	1.9	.3	25	0	3	22	0	0	0	0	0
1522	2.8	.9	23	0	1	8	8	6	0	0	0
1514	2.8	.8	25	0	1	9	10	5	0	0	0
1507	3.8	1.2	25	0	1	1	8	8	5	2	0
1734	6	0	2	0	0	0	0	0	0	2	0
1739	2	0	3	0	0	3	0	0	0	0	0
1200	1.1	.4	25	1	21	3	0	0	0	0	0
1178	1.4	.8	25	0	18	5	1	1	0	0	0
1163	1.2	.4	25	0	21	4	0	0	0	0	0
1175	1.4	.5	25	0	16	9	0	0	0	0	0
1061	1.4	.7	25	1	14	8	2	0	0	0	0
1191	1.5	.5	25	0	13	12	0	0	0	0	0
1189	1.3	.5	25	0	18	7	0	0	0	0	0
1173	1.3	.5	25	0	17	8	0	0	0	0	0
1198	1.3	.5	25	0	17	8	0	0	0	0	0
1201	1.3	.5	25	0	18	7	0	0	0	0	0
1313	2.2	.6	25	0	2	17	5	1	0	0	0
1303	2.6	.6	25	0	0	12	11	2	0	0	0
1297	1.9	.9	25	0	9	11	3	2	0	0	0
1299	1.4	.9	18	4	3	10	1	0	0	0	0
1320	3.5	.6	4	0	0	0	2	2	0	0	0
1674	2.6	.5	5	0	0	2	3	0	0	0	0
1684	2	0	2	0	0	2	0	0	0	0	0
1681	2.9	1	13	0	2	0	8	3	0	0	0
1139	1.4	.5	5	0	3	2	0	0	0	0	0
1140	1.9	.4	7	0	1	6	0	0	0	0	0
1145	1.2	.8	25	4	15	4	2	0	0	0	0
1067	1.7	.7	25	1	9	12	3	0	0	0	0
1034	2.6	1.3	19	1	3	5	5	4	1	0	0
1209	1.7	.5	13	0	4	9	0	0	0	0	0
1057	2.9	.8	25	0	1	6	13	5	0	0	0
1216	1.6	.5	5	0	2	3	0	0	0	0	0

Continued...

Table 2-5. Continued.

SAMPLE NO.	AGE			AGE (YEARS)							
	MEAN	SD	NO.	0+	1+	2+	3+	4+	5+	6+	7+
1149	2	0	2	0	0	2	0	0	0	0	0
1164	2	.7	25	0	6	14	5	0	0	0	0
1155	1.4	.5	7	0	4	3	0	0	0	0	0
1064	2.2	.9	25	0	6	9	8	2	0	0	0
1060	1.4	.8	25	0	19	3	2	1	0	0	0
1268	2	0	2	0	0	2	0	0	0	0	0
1210	2.3	.9	16	0	5	2	9	0	0	0	0
1202	2	1	12	0	5	3	3	1	0	0	0
1069	1.6	.6	25	0	12	11	2	0	0	0	0
1054	1.1	1	25	6	14	4	0	0	1	0	0
1199	1.3	1.2	3	1	0	2	0	0	0	0	0
1239	2.1	.8	25	0	4	17	3	0	1	0	0
1055	1	0	2	0	2	0	0	0	0	0	0
1261	1.7	.9	25	0	13	8	3	1	0	0	0
1052	3.5	.8	25	0	0	3	8	13	1	0	0
1081	1.3	.6	19	1	11	7	0	0	0	0	0
1150	1.4	.6	25	1	14	10	0	0	0	0	0
1156	3.3	.9	25	1	0	0	14	9	1	0	0
1264	2	.5	25	0	3	19	3	0	0	0	0
1138	2.5	.6	25	0	0	13	11	1	0	0	0
1284	2.3	1.3	25	1	5	12	3	2	1	1	0
1240	2.1	1	25	0	8	10	4	3	0	0	0
1030	2	0	3	0	0	3	0	0	0	0	0
1147	3.7	.7	10	0	0	1	1	8	0	0	0
1250	2	1	25	0	7	13	3	1	1	0	0
1038	2.2	.8	19	0	4	7	8	0	0	0	0
1256	1.6	.9	25	0	14	7	3	1	0	0	0
1154	2.7	1.2	25	0	4	9	6	3	3	0	0
1147	2	1	3	0	1	1	1	0	0	0	0
1241	1.7	.6	25	0	9	15	1	0	0	0	0
1232	1.3	.5	25	0	17	8	0	0	0	0	0
1234	2.9	.9	25	0	1	8	9	7	0	0	0
1276	2	0	2	0	0	2	0	0	0	0	0
1265	2.2	.9	12	0	2	8	0	2	0	0	0
1279	2.2	.8	19	0	2	13	2	2	0	0	0
1152	3.1	.7	14	0	0	2	8	4	0	0	0
1253	1.7	.6	25	0	10	13	2	0	0	0	0
1281	2	.5	25	0	3	20	2	0	0	0	0
1029	2.5	.7	22	0	0	12	8	2	0	0	0
1204	1.8	.6	25	0	7	16	2	0	0	0	0
1293	2.6	1	25	0	5	5	11	4	0	0	0

Continued...

Table 2-5. Continued.

SAMPLE NO.	AGE			AGE (YEARS)							
	MEAN	SD	NO.	0+	1+	2+	3+	4+	5+	6+	7+
1304	1.6	.6	25	0	12	12	1	0	0	0	0
1291	1.6	.6	25	0	11	12	2	0	0	0	0
1288	1.8	.7	25	0	9	13	3	0	0	0	0
1322	2	1	25	0	9	8	6	2	0	0	0
1026	3.2	1.1	25	0	2	3	11	6	3	0	0
1048	1.8	1	25	0	10	12	1	1	1	0	0
1050	2.2	1.2	25	0	10	3	8	4	0	0	0
1056	1.3	.5	25	0	18	7	0	0	0	0	0
1143	1.3	.6	25	1	16	7	1	0	0	0	0
1153	1.6	.9	25	1	14	6	3	1	0	0	0
1165	1.8	.5	25	1	3	21	0	0	0	0	0
1168	2.6	1.4	25	1	5	8	2	7	2	0	0
1185	1.3	.6	25	1	17	6	1	0	0	0	0
1196	2	.6	25	0	4	16	5	0	0	0	0
1205	2	1.1	25	1	9	8	4	3	0	0	0
1207	1.2	.6	21	2	12	7	0	0	0	0	0
1218	1.7	.7	25	1	8	14	2	0	0	0	0
1245	1.8	.5	17	1	1	15	0	0	0	0	0
1260	1.6	.7	25	1	10	12	2	0	0	0	0
1271	2.5	.7	15	0	0	9	4	2	0	0	0
1278	2	.7	25	1	2	20	1	1	0	0	0
1033	1	0	2	0	2	0	0	0	0	0	0
1044	2.7	.8	25	0	3	3	17	2	0	0	0
1053	1.9	1	14	0	6	6	0	2	0	0	0
1065	3.1	.8	25	0	1	3	13	8	0	0	0
1068	1.3	.6	25	0	18	6	1	0	0	0	0
1070	3	1.2	4	0	0	2	0	2	0	0	0
1074	1.7	.9	25	0	12	10	1	2	0	0	0
1084	3	.7	25	0	0	5	14	6	0	0	0
1088	2.6	.8	25	0	2	9	12	2	0	0	0
1090	2.4	.8	25	0	2	14	7	2	0	0	0
1144	2	0	18	0	0	18	0	0	0	0	0
1160	1.8	.8	25	0	11	10	3	1	0	0	0
1167	1.2	.4	10	0	8	2	0	0	0	0	0
1169	2.7	1.4	25	0	6	7	3	6	3	0	0
1182	2.8	1.2	25	0	6	2	8	9	0	0	0
1187	1.2	.4	25	0	20	5	0	0	0	0	0
1208	1.6	.9	25	1	13	7	3	1	0	0	0
1262	1.4	.6	25	1	14	9	1	0	0	0	0
1267	1.8	1	25	0	13	7	2	3	0	0	0
1277	1.2	.7	25	3	16	5	1	0	0	0	0

Continued...

Table 2-5. Continued.

SAMPLE NO.	AGE			AGE (YEARS)							
	MEAN	SD	NO.	0+	1+	2+	3+	4+	5+	6+	7+
1283	1.5	.7	25	0	14	9	2	0	0	0	0
1611	2.2	.5	25	0	0	22	2	1	0	0	0
1612	2.2	.6	25	0	1	20	3	1	0	0	0
1615	2.6	.8	25	0	0	14	7	4	0	0	0
1617	2.2	.6	25	0	0	21	2	2	0	0	0
1618	2.7	.5	25	0	0	8	16	1	0	0	0
1621	2	.5	25	0	3	21	0	1	0	0	0
1622	2.7	.6	25	0	0	9	15	1	0	0	0
1623	2.4	.8	25	0	0	17	6	1	1	0	0
1636	2.4	.8	25	0	3	12	8	2	0	0	0
1637	2.2	.5	25	0	0	20	4	1	0	0	0
1644	2.3	.9	25	0	3	16	3	2	1	0	0
1648	2.2	.6	25	0	1	19	4	1	0	0	0
1650	2.1	.6	25	0	2	19	3	1	0	0	0
1666	2.4	.6	25	0	1	14	9	1	0	0	0
1667	2.5	.9	13	0	1	7	3	2	0	0	0
1307	2	.9	25	1	6	11	6	1	0	0	0
1314	2.8	1.1	25	0	3	8	6	7	1	0	0
1295	3.5	.8	25	0	0	3	9	11	2	0	0
1308	2.7	.8	24	0	0	13	6	5	0	0	0
1310	2.1	1	25	0	8	10	4	3	0	0	0
1319	2.6	.7	25	0	1	10	12	2	0	0	0
1651	3.4	.6	25	0	0	1	14	10	0	0	0
1649	2.3	.7	25	0	1	18	4	2	0	0	0
1627	2.4	.8	25	0	3	12	8	2	0	0	0
1643	1.9	.3	25	0	2	23	0	0	0	0	0
1614	2.8	.8	25	0	2	5	14	4	0	0	0
1668	3.9	1.1	19	0	0	2	5	7	3	2	0
1653	2.1	.5	25	0	1	22	1	1	0	0	0
1642	3.4	.8	25	0	0	1	16	5	3	0	0
1655	2.6	.7	25	0	2	7	15	1	0	0	0
1664	1.8	.5	4	0	1	3	0	0	0	0	0
1662	2.5	.6	25	0	0	13	11	1	0	0	0
1645	2.4	.8	25	0	1	14	9	0	1	0	0
1652	2.8	.8	25	0	1	8	11	5	0	0	0
1669	2	.7	25	1	4	15	5	0	0	0	0
1613	2.6	.8	25	0	0	13	9	2	1	0	0
1646	2.4	.9	25	0	3	12	8	1	1	0	0
1663	2.1	.4	21	0	0	18	3	0	0	0	0
1610	1	0	2	0	2	0	0	0	0	0	0
1619	2.4	.8	25	0	1	15	6	3	0	0	0
1616	2.4	.7	25	0	2	13	9	1	0	0	0

Continued...

Table 2-5. Concluded.

SAMPLE	AGE			AGE (YEARS)							
NO.	MEAN	SD	NO.	0+	1+	2+	3+	4+	5+	6+	7+
1639	2	.2	25	0	0	24	1	0	0	0	0
1641	2.2	.4	25	0	0	21	4	0	0	0	0
1657	2.6	.8	25	0	1	10	11	3	0	0	0
1658	1.8	.5	4	0	1	3	0	0	0	0	0
1656	2.9	.7	25	0	0	7	13	5	0	0	0
1661	2.4	.6	25	0	1	14	10	0	0	0	0
1311	2.9	1.4	9	0	1	3	3	0	2	0	0
1294	3.5	.8	25	0	1	0	10	13	1	0	0
1301	2	.5	25	0	3	20	2	0	0	0	0
1880	2.2	.7	36	0	3	25	5	3	0	0	0
1881	2	.4	13	0	1	11	1	0	0	0	0
1882	2.2	.5	39	0	1	28	10	0	0	0	0
1883	2.4	.7	44	0	2	25	15	2	0	0	0
1884	2.2	.4	5	0	0	4	1	0	0	0	0
1885	2.3	.6	3	0	0	2	1	0	0	0	0
1886	2.2	.9	28	0	4	18	4	1	1	0	0
1887	3.2	.9	47	0	0	11	18	16	2	0	0
1888	1.8	.8	27	0	11	10	6	0	0	0	0
1889	3	0	1	0	0	0	1	0	0	0	0
1877	.9	1.4	9	6	0	1	2	0	0	0	0
1879	2.4	1.3	5	1	0	0	4	0	0	0	0
1876	2	1	7	1	0	4	2	0	0	0	0
1878	1.2	.8	19	4	8	7	0	0	0	0	0

Table 2-6. Age-frequency distribution for Arctic cod otliths found in northern fulmar samples.

SAMPLE NO.	AGE			AGE (YEARS)							
	MEAN	SD	NO.	0+	1+	2+	3+	4+	5+	6+	7+
9360	2	0	1	0	0	1	0	0	0	0	0
9361	3	0	1	0	0	0	1	0	0	0	0
9362	0	0	2	2	0	0	0	0	0	0	0
9363	3	0	1	0	0	0	1	0	0	0	0
9364	2.5	.7	2	0	0	1	1	0	0	0	0
9365	1	0	2	0	2	0	0	0	0	0	0
9366	3.3	1.7	4	0	1	0	1	1	1	0	0
9367	3	1.2	4	0	0	2	0	2	0	0	0
9368	2	0	2	0	0	2	0	0	0	0	0
9369	2	0	1	0	0	1	0	0	0	0	0
9370	2.8	.4	5	0	0	1	4	0	0	0	0
9371	3	0	2	0	0	0	2	0	0	0	0
9372	4.5	.6	4	0	0	0	0	2	2	0	0
9192	4	0	2	0	0	0	0	2	0	0	0
9194	3	0	2	0	0	0	2	0	0	0	0
9195	4	0	1	0	0	0	0	1	0	0	0
9198	1	0	1	0	1	0	0	0	0	0	0
9201	4	0	2	0	0	0	0	2	0	0	0
9202	4.7	.5	6	0	0	0	0	2	4	0	0
9204	5	0	2	0	0	0	0	0	2	0	0
9211	2	0	1	0	0	1	0	0	0	0	0
9213	3.7	.6	3	0	0	0	1	2	0	0	0
9215	3.5	.5	8	0	0	0	4	4	0	0	0
9216	4	1	9	0	0	0	4	1	4	0	0

Table 2-7. Age-frequency distribution for Arctic cod otoliths found in thick-billed murre samples.

SAMPLE NO.	AGE			AGE (YEARS)							
	MEAN	SD	NO.	0+	1+	2+	3+	4+	5+	6+	7+
9022	0	0	2	2	0	0	0	0	0	0	0
9023	3.4	.5	5	0	0	0	3	2	0	0	0
9024	3.5	.7	2	0	0	0	1	1	0	0	0
9025	0	0	22	22	0	0	0	0	0	0	0
9026	1	0	1	0	1	0	0	0	0	0	0
9027	.3	.5	14	10	4	0	0	0	0	0	0
9028	.9	.5	12	2	9	1	0	0	0	0	0
9029	3.3	.8	7	0	0	1	3	3	0	0	0
9030	2.7	.8	7	0	1	0	6	0	0	0	0
9031	2.6	2.4	7	3	0	0	0	2	2	0	0
9032	.1	.4	21	18	3	0	0	0	0	0	0
9033	0	0	5	5	0	0	0	0	0	0	0
9034	.4	.5	15	9	6	0	0	0	0	0	0
9035	3	0	2	0	0	0	2	0	0	0	0
9036	1.8	1.8	6	1	3	0	1	0	1	0	0
9037	2	1	9	0	4	1	4	0	0	0	0
9038	3	0	1	0	0	0	1	0	0	0	0
9039	3	0	1	0	0	0	1	0	0	0	0
9040	3.2	.4	5	0	0	0	4	1	0	0	0
9041	1.3	1.5	3	1	1	0	1	0	0	0	0
9042	1	0	3	0	3	0	0	0	0	0	0
9236	3	0	1	0	0	0	1	0	0	0	0
9043	1	.6	6	1	4	1	0	0	0	0	0
9237	0	0	1	1	0	0	0	0	0	0	0
9044	.6	.5	5	2	3	0	0	0	0	0	0
9045	2	0	2	0	0	2	0	0	0	0	0
9046	3	0	2	0	0	0	2	0	0	0	0
9047	1	0	1	0	1	0	0	0	0	0	0
9048	1	1.4	2	1	0	1	0	0	0	0	0
9049	4	0	1	0	0	0	0	1	0	0	0
9050	1	0	1	0	1	0	0	0	0	0	0
9051	1	0	1	0	1	0	0	0	0	0	0
9052	5	0	1	0	0	0	0	0	1	0	0
9053	2	1.4	2	0	1	0	1	0	0	0	0
9054	4	0	1	0	0	0	0	1	0	0	0
9055	1.1	.5	32	2	27	2	1	0	0	0	0
9056	.7	.8	31	13	16	0	2	0	0	0	0
9057	.4	.5	13	8	5	0	0	0	0	0	0
9058	.7	.6	3	1	2	0	0	0	0	0	0
9059	1	0	1	0	1	0	0	0	0	0	0

Continued...

Table 2-7. Continued.

SAMPLE NO.	AGE			AGE (YEARS)							
	MEAN	SD	NO.	0+	1+	2+	3+	4+	5+	6+	7+
9060	.8	1	30	11	17	0	0	2	0	0	0
9061	1.1	.5	11	1	8	2	0	0	0	0	0
9062	.5	.5	20	10	10	0	0	0	0	0	0
9063	.7	.6	3	1	2	0	0	0	0	0	0
9064	.5	.6	26	14	10	2	0	0	0	0	0
9065	1	0	3	0	3	0	0	0	0	0	0
9066	.7	.9	12	6	5	0	1	0	0	0	0
9067	.8	.5	8	2	6	0	0	0	0	0	0
9068	.9	1.4	15	8	4	1	1	0	1	0	0
9069	.5	.5	11	5	6	0	0	0	0	0	0
9070	.3	.5	16	11	5	0	0	0	0	0	0
9071	.6	.8	18	9	8	0	1	0	0	0	0
9072	.9	.7	25	6	16	2	1	0	0	0	0
9073	.9	1.1	17	6	9	0	1	1	0	0	0
9074	.4	.5	17	10	7	0	0	0	0	0	0
9075	.6	.5	32	14	18	0	0	0	0	0	0
9076	.6	.7	30	14	15	0	1	0	0	0	0
9077	.4	.5	18	11	7	0	0	0	0	0	0
9078	.7	.5	7	2	5	0	0	0	0	0	0
9079	.3	.7	39	30	8	0	0	1	0	0	0
9080	.3	.8	25	22	1	0	2	0	0	0	0
9081	.3	.5	39	29	9	1	0	0	0	0	0
9082	.5	.6	25	14	10	1	0	0	0	0	0
9083	.2	.4	71	55	16	0	0	0	0	0	0
9084	.7	1	38	20	14	1	1	2	0	0	0
9085	.2	.4	30	23	7	0	0	0	0	0	0
9086	.4	.7	57	40	15	1	0	1	0	0	0
9087	.4	.5	26	15	11	0	0	0	0	0	0
9088	.5	1	41	27	10	2	0	2	0	0	0
9089	.3	.9	20	17	2	0	0	1	0	0	0
9090	.4	.9	12	9	2	0	1	0	0	0	0
9091	.3	.5	6	4	2	0	0	0	0	0	0
9092	.2	.4	77	58	19	0	0	0	0	0	0
9000	1	0	1	0	1	0	0	0	0	0	0
9001	3	0	2	0	0	0	2	0	0	0	0
9002	5	0	1	0	0	0	0	0	1	0	0
9003	3	0	1	0	0	0	1	0	0	0	0
9004	2.3	.6	3	0	0	2	1	0	0	0	0
9005	2	0	2	0	0	2	0	0	0	0	0
9006	3	0	1	0	0	0	1	0	0	0	0
9007	1.3	.6	3	0	2	1	0	0	0	0	0

Continued...

Table 2-7. Continued.

SAMPLE NO.	AGE			AGE (YEARS)							
	MEAN	SD	NO.	0+	1+	2+	3+	4+	5+	6+	7+
9008	1.5	.6	4	0	2	2	0	0	0	0	0
9009	3	0	2	0	0	0	2	0	0	0	0
9010	3	0	2	0	0	0	2	0	0	0	0
9011	3	0	2	0	0	0	2	0	0	0	0
9012	2	0	2	0	0	2	0	0	0	0	0
9013	1.3	.6	3	0	2	1	0	0	0	0	0
9014	1	0	6	0	6	0	0	0	0	0	0
9015	3	0	1	0	0	0	1	0	0	0	0
9016	2	1.4	2	0	1	0	1	0	0	0	0
9017	1	0	1	0	1	0	0	0	0	0	0
9018	4	0	2	0	0	0	0	2	0	0	0
9019	2	0	1	0	0	1	0	0	0	0	0
9021	4	0	2	0	0	0	0	2	0	0	0
9217	1.5	.6	36	0	20	14	2	0	0	0	0
9218	2	0	7	0	0	7	0	0	0	0	0
9219	2.3	.8	17	0	2	9	5	1	0	0	0
9220	2.5	.7	2	0	0	1	1	0	0	0	0
9221	1	0	1	0	1	0	0	0	0	0	0
9222	1.8	.4	5	0	1	4	0	0	0	0	0
9223	1.7	.5	20	0	6	14	0	0	0	0	0
9224	1.6	.5	5	0	2	3	0	0	0	0	0
9225	1.7	.8	6	1	0	5	0	0	0	0	0
9226	.8	.6	15	4	10	1	0	0	0	0	0
9227	1.3	.6	3	0	2	1	0	0	0	0	0
9228	1.2	.5	27	0	23	3	1	0	0	0	0
9229	1.4	.8	28	1	19	3	5	0	0	0	0
9230	2	0	3	0	0	3	0	0	0	0	0
9231	1.5	.7	2	0	1	1	0	0	0	0	0
9232	2.1	1.5	7	0	4	0	1	2	0	0	0
9233	2.5	.7	2	0	0	1	1	0	0	0	0
9234	1.5	.7	2	0	1	1	0	0	0	0	0
9235	1.9	.8	16	0	5	9	1	1	0	0	0
9238	2	.7	10	0	2	6	2	0	0	0	0
9239	1.5	.7	2	0	1	1	0	0	0	0	0
9240	1	0	1	0	1	0	0	0	0	0	0
9241	1.3	.5	7	0	5	2	0	0	0	0	0
9242	2.3	.5	6	0	0	4	2	0	0	0	0
9243	1.3	.6	21	1	13	7	0	0	0	0	0
9244	2	0	2	0	0	2	0	0	0	0	0
9245	1.1	.5	42	1	36	4	1	0	0	0	0
9246	1.1	.3	16	0	14	2	0	0	0	0	0

Continued...

Table 2-7. Continued.

SAMPLE NO.	AGE			AGE (YEARS)							
	MEAN	SD	NO.	0+	1+	2+	3+	4+	5+	6+	7+
9247	1.5	.7	2	0	1	1	0	0	0	0	0
9248	1	.5	16	2	12	2	0	0	0	0	0
9249	2.1	1.2	12	0	5	3	2	2	0	0	0
9250	1.5	1.3	28	3	17	2	4	0	2	0	0
9251	1.7	.6	3	0	1	2	0	0	0	0	0
9252	2.3	1.2	3	0	1	0	2	0	0	0	0
9253	1.2	.8	37	5	24	5	3	0	0	0	0
9254	1.2	.8	17	1	13	2	0	1	0	0	0
9255	1.9	1.3	18	1	6	9	0	0	2	0	0
9256	1.2	.8	51	4	39	5	1	2	0	0	0
9257	2	1	3	0	1	1	1	0	0	0	0
9258	2.3	1.2	20	0	8	2	8	1	1	0	0
9259	1	0	2	0	2	0	0	0	0	0	0
9260	1.7	.6	19	0	7	11	1	0	0	0	0
9261	1.8	.8	10	0	4	4	2	0	0	0	0
9262	2.3	.7	10	0	1	5	4	0	0	0	0
9263	2	0	1	0	0	1	0	0	0	0	0
9264	1.6	.6	39	1	15	22	1	0	0	0	0
9265	2	0	1	0	0	1	0	0	0	0	0
9266	2	1.4	4	0	2	1	0	1	0	0	0
9267	1.8	.5	4	0	1	3	0	0	0	0	0
9268	2.1	.7	10	0	2	5	3	0	0	0	0
9093	2.5	2.1	2	0	1	0	0	1	0	0	0
9094	.8	.5	4	1	3	0	0	0	0	0	0
9095	1	.8	4	1	2	1	0	0	0	0	0
9096	1.2	.7	25	4	11	10	0	0	0	0	0
9097	1.3	.7	22	3	9	10	0	0	0	0	0
9098	1.1	.4	14	0	12	2	0	0	0	0	0
9099	1.4	.6	66	3	36	27	0	0	0	0	0
9100	.5	.5	21	11	10	0	0	0	0	0	0
9101	2	.6	11	0	2	7	2	0	0	0	0
9102	2	0	3	0	0	3	0	0	0	0	0
9103	2.2	.8	5	0	1	2	2	0	0	0	0
9104	2	0	2	0	0	2	0	0	0	0	0
9105	1.5	.5	11	0	6	5	0	0	0	0	0
9106	1.7	.6	3	0	1	2	0	0	0	0	0
9107	4	0	1	0	0	0	0	1	0	0	0
9108	1	0	1	0	1	0	0	0	0	0	0
9109	1	0	1	0	1	0	0	0	0	0	0
9110	1	0	2	0	2	0	0	0	0	0	0
9111	1	0	3	0	3	0	0	0	0	0	0

Continued...

Table 2-7. Continued.

SAMPLE NO.	AGE			AGE (YEARS)							
	MEAN	SD	NO.	0+	1+	2+	3+	4+	5+	6+	7+
9112	2	0	1	0	0	1	0	0	0	0	0
9113	3	0	2	0	0	0	2	0	0	0	0
9114	1.5	.6	4	0	2	2	0	0	0	0	0
9115	.8	.4	5	1	4	0	0	0	0	0	0
9116	4	0	1	0	0	0	0	1	0	0	0
9117	3	0	2	0	0	0	2	0	0	0	0
9118	2	0	1	0	0	1	0	0	0	0	0
9119	1	0	1	0	1	0	0	0	0	0	0
9120	4	0	1	0	0	0	0	1	0	0	0
9121	2.8	.4	5	0	0	1	4	0	0	0	0
9122	1	0	1	0	1	0	0	0	0	0	0
9123	1	0	4	0	4	0	0	0	0	0	0
9124	4	0	2	0	0	0	0	2	0	0	0
9125	.8	.5	4	1	3	0	0	0	0	0	0
9127	4	0	2	0	0	0	0	2	0	0	0
9128	2	0	3	0	0	3	0	0	0	0	0
9129	3.3	.5	6	0	0	0	4	2	0	0	0
9189	3	0	2	0	0	0	2	0	0	0	0
9130	1	0	1	0	1	0	0	0	0	0	0
9131	3	0	1	0	0	0	1	0	0	0	0
9132	1.3	.6	3	0	2	1	0	0	0	0	0
9134	1	0	1	0	1	0	0	0	0	0	0
9135	4	0	1	0	0	0	0	1	0	0	0
9136	2.3	1.2	3	0	1	0	2	0	0	0	0
9141	1.3	.6	3	0	2	1	0	0	0	0	0
9143	0	0	2	2	0	0	0	0	0	0	0
9144	4	0	1	0	0	0	0	1	0	0	0
9146	1.3	1.2	3	1	0	2	0	0	0	0	0
9147	3	0	2	0	0	0	2	0	0	0	0
9148	2	0	1	0	0	1	0	0	0	0	0
9150	0	0	1	1	0	0	0	0	0	0	0
9151	1	0	1	0	1	0	0	0	0	0	0
9152	1	0	1	0	1	0	0	0	0	0	0
9153	2	0	1	0	0	1	0	0	0	0	0
9154	0	0	1	1	0	0	0	0	0	0	0
9155	1	0	1	0	1	0	0	0	0	0	0
9156	1.2	.4	11	0	9	2	0	0	0	0	0
9157	2.8	.5	4	0	0	1	3	0	0	0	0
9158	1	0	1	0	1	0	0	0	0	0	0
9159	3	0	1	0	0	0	1	0	0	0	0
9160	1.8	.7	9	0	3	5	1	0	0	0	0

Continued...

Table 2-7. Continued.

SAMPLE NO.	AGE			AGE (YEARS)							
	MEAN	SD	NO.	0+	1+	2+	3+	4+	5+	6+	7+
9161	3	0	1	0	0	0	1	0	0	0	0
9162	.5	.6	4	2	2	0	0	0	0	0	0
9163	1	0	2	0	2	0	0	0	0	0	0
9164	1.5	.6	4	0	2	2	0	0	0	0	0
9165	1.3	.5	4	0	3	1	0	0	0	0	0
9166	2	0	1	0	0	1	0	0	0	0	0
9167	3	0	1	0	0	0	1	0	0	0	0
9170	.9	.4	7	1	6	0	0	0	0	0	0
9171	2	0	3	0	0	3	0	0	0	0	0
9173	2.3	1.2	3	0	1	0	2	0	0	0	0
9175	2	0	1	0	0	1	0	0	0	0	0
9176	2.3	1.4	6	0	2	2	0	2	0	0	0
9177	2	0	2	0	0	2	0	0	0	0	0
9178	1	0	1	0	1	0	0	0	0	0	0
9179	3	0	2	0	0	0	2	0	0	0	0
9180	1	0	1	0	1	0	0	0	0	0	0
9181	2	0	1	0	0	1	0	0	0	0	0
9182	2	0	2	0	0	2	0	0	0	0	0
9183	2	0	3	0	0	3	0	0	0	0	0
9184	1.7	.6	3	0	1	2	0	0	0	0	0
9185	3.3	1	4	0	0	1	1	2	0	0	0
9186	1	0	1	0	1	0	0	0	0	0	0
9187	3.8	.4	5	0	0	0	1	4	0	0	0
9188	2.3	.6	3	0	0	2	1	0	0	0	0
9335	1.9	.6	33	0	6	23	4	0	0	0	0
9336	1.7	.5	18	0	6	12	0	0	0	0	0
9337	1.8	.4	12	0	2	10	0	0	0	0	0
9338	1.9	.5	28	0	4	22	2	0	0	0	0
9339	2	0	9	0	0	9	0	0	0	0	0
9340	1	0	3	0	3	0	0	0	0	0	0
9341	3	0	1	0	0	0	1	0	0	0	0
9342	1	0	1	0	1	0	0	0	0	0	0
9343	2	0	2	0	0	2	0	0	0	0	0
9344	2	0	1	0	0	1	0	0	0	0	0
9345	1	0	2	0	2	0	0	0	0	0	0
9346	1	0	5	0	5	0	0	0	0	0	0
9347	4	0	1	0	0	0	0	1	0	0	0
9348	2	0	3	0	0	3	0	0	0	0	0
9349	3	0	4	0	0	0	4	0	0	0	0
9350	2	1.1	6	0	3	0	3	0	0	0	0
9351	1	0	1	0	1	0	0	0	0	0	0

Continued...

Table 2-7. Continued.

SAMPLE NO.	AGE			AGE (YEARS)							
	MEAN	SD	NO.	0+	1+	2+	3+	4+	5+	6+	7+
9352	2.6	1	16	0	3	4	6	3	0	0	0
9353	1.2	.8	6	1	3	2	0	0	0	0	0
9354	1.5	.6	4	0	2	2	0	0	0	0	0
9355	3	0	1	0	0	0	1	0	0	0	0
9356	.9	.6	26	6	17	3	0	0	0	0	0
9357	1	0	1	0	1	0	0	0	0	0	0
9358	1	0	2	0	2	0	0	0	0	0	0
9269	2	0	2	0	0	2	0	0	0	0	0
9270	2	0	1	0	0	1	0	0	0	0	0
9271	4	0	1	0	0	0	0	1	0	0	0
9272	2	0	1	0	0	1	0	0	0	0	0
9273	6	0	2	0	0	0	0	0	0	2	0
9274	4	0	1	0	0	0	0	1	0	0	0
9276	0	0	1	1	0	0	0	0	0	0	0
9277	3	0	1	0	0	0	1	0	0	0	0
9278	2.7	.6	3	0	0	1	2	0	0	0	0
9279	4	0	1	0	0	0	0	1	0	0	0
9280	3	0	1	0	0	0	1	0	0	0	0
9281	2	0	1	0	0	1	0	0	0	0	0
9283	1	0	1	0	1	0	0	0	0	0	0
9284	3	0	2	0	0	0	2	0	0	0	0
9286	2	0	1	0	0	1	0	0	0	0	0
9287	2	0	1	0	0	1	0	0	0	0	0
9288	3	0	1	0	0	0	1	0	0	0	0
9290	2	0	1	0	0	1	0	0	0	0	0
9291	3	0	1	0	0	0	1	0	0	0	0
9292	3	0	1	0	0	0	1	0	0	0	0
9294	3	0	1	0	0	0	1	0	0	0	0
9295	2	0	1	0	0	1	0	0	0	0	0
9296	2	0	1	0	0	1	0	0	0	0	0
9297	2	0	3	0	0	3	0	0	0	0	0
9299	2	0	1	0	0	1	0	0	0	0	0
9303	3	0	1	0	0	0	1	0	0	0	0
9306	2	0	1	0	0	1	0	0	0	0	0
9308	1	0	1	0	1	0	0	0	0	0	0
9310	2	0	3	0	0	3	0	0	0	0	0
9311	2	0	1	0	0	1	0	0	0	0	0
9315	2.5	.7	2	0	0	1	1	0	0	0	0
9318	3	0	1	0	0	0	1	0	0	0	0
9319	1.5	.7	2	0	1	1	0	0	0	0	0
9321	2	1	3	0	1	1	1	0	0	0	0

Continued...

Table 2-7. Concluded.

SAMPLE NO.	AGE			AGE (YEARS)							
	MEAN	SD	NO.	0+	1+	2+	3+	4+	5+	6+	7+
9322	2	0	1	0	0	1	0	0	0	0	0
9323	1	0	1	0	1	0	0	0	0	0	0
9324	1	0	1	0	1	0	0	0	0	0	0
9325	2	0	1	0	0	1	0	0	0	0	0
9327	3	0	2	0	0	0	2	0	0	0	0
9328	0	0	1	1	0	0	0	0	0	0	0
9330	2	0	2	0	0	2	0	0	0	0	0
9332	2	0	1	0	0	1	0	0	0	0	0
9333	2	0	3	0	0	3	0	0	0	0	0
9334	3	0	2	0	0	0	2	0	0	0	0

APPENDIX 3: READABILITY AND ABRASION VALUES FOR ARCTIC COD OTOLITHS FOUND IN VARIOUS PREDATOR SAMPLES

Table 3-1. Readability and abrasion values for Arctic cod otoliths in ringed seal samples.

Region	Age Grouping (location)	Season[a]	Year	Readability					Abrasion			
				0	1	2	3	4	1	2	3	4
Labrador (Makkovik)	adult	haul out	1979	27	45	38	7	0	63	54	0	0
Labrador (Makkovik)	adult	open water	1979	0	90	42	4	0	115	17	4	0
Resolute Bay	all ages	early/late winter	1978-79	72	33	12	4	0	121	0	0	0
Grise Fiord	0+	open water	1979	51	0	10	10	1	72	0	0	0
Grise Fiord	0+	late winter	1979	30	1	47	15	4	96	0	1	0
Grise Fiord	juvenile	early winter	1978	47	7	41	25	1	116	2	3	0
Grise Fiord	juvenile	haul out	1979	45	26	11	20	5	64	42	1	0
Grise Fiord	juvenile	open water	1979	0	0	46	2	0	48	0	0	0
Grise Fiord	juvenile	early winter	1979	87	8	12	12	4	123	0	0	0
Grise Fiord	adult	early winter	1978	52	2	7	9	3	71	2	0	0
Grise Fiord	adult	open water	1979	2	0	3	0	0	5	0	0	0
Pond Inlet (Kounuk)	juvenile	open water	1978	0	66	53	6	0	109	16	0	0
Pond Inlet (Kounuk)	adult	open water	1978	1	64	47	13	0	107	18	0	0
Pond Inlet (Kounuk)	adult	early winter	1978	0	0	94	3	0	92	5	0	0
Pond Inlet (Kounuk)	adult	open water	1979	0	5	11	4	0	17	3	0	0
Pond Inlet (village)	0+ (inshore)	open water	1978	36	9	93	59	11	193	7	4	4
Pond Inlet (village	juvenile (inshore)	open water	1978	43	53	136	44	3	267	11	0	1
Pond Inlet (village)	juvenile (offshore)	open water	1978	0	10	35	5	0	50	0	0	0
Pond Inlet (village)	immature (inshore)	open water	1978	12	68	94	84	24	273	7	2	0
Pond Inlet (village)	immature (offshore)	open water	1978	32	7	7	1	0	47	0	0	0
Pond Inlet (village)	immature	early winter	1978	0	0	108	17	0	119	6	0	0
Pond Inlet (village)	adult (inshore)	open water	1978	18	157	236	37	0	441	7	0	0
Pond Inlet (village)	adult (offshore)	open water	1978	3	121	262	14	3	394	9	0	0
Pond Inlet (village)	adult	early winter	1978	7	28	90	23	1	147	2	0	0
Pond Inlet (ice edge)	juvenile	late winter	1979	4	5	233	6	0	239	9	0	0
Pond Inlet (ice edge)	immature	late winter	1979	29	3	276	19	0	320	7	0	0
Pond Inlet (ice edge)	adult	early winter	1978	0	0	55	4	0	58	0	0	1
Pond Inlet (ice edge)	adult	late winter	1979	36	27	258	37	5	363	0	0	0
Pond Inlet (ice edge)	all ages	haul out	1979	19	63	153	47	1	272	11	0	0

[a] Seasons are defined in Results section.

Table 3-2. Readability and abrasion values for Arctic cod otoliths from ringed seal stomachs with differing amounts of food.

Volume of food in stomach	No. of otoliths in stomach	Readability					Abrasion			
		0	1	2	3	4	1	2	3	4
<10% full	<25	15	9	22	3	0	49	0	0	0
	25-100	113	24	121	12	0	220	50	0	0
	>100	9	166	187	19	0	266	114	1	0
10-40% full	<25	0	8	25	3	0	35	1	0	0
	25-100	83	63	82	17	0	233	12	0	0
	>100	51	64	313	21	0	443	5	1	0
>40% full	25-100	35	20	126	28	2	207	4	0	0
	>100	23	295	445	125	1	750	138	1	0

Table 3-3. Readability and abrasion values for Arctic cod otoliths from white whale, bearded seal, narwhal and harp seal stomachs.

Region	Age Grouping	Season[a]	Year	Readability 0	Readability 1	Readability 2	Readability 3	Readability 4	Abrasion 1	Abrasion 2	Abrasion 3	Abrasion 4
White whale												
Creswell Bay	all ages	open water	1975	0	10	72	43	0	43	60	21	1
Grise Fiord	all ages	open water	1978	0	93	32	0	0	110	13	2	0
Bearded seal												
Grise Fiord	all ages	open water	1978-79	8	12	71	32	2	99	26	0	0
Pond Inlet (Kounuk + village)	all ages	open water	1978-79	8	5	86	43	5	140	5	2	0
Clyde River	all ages	open water	1979-80	14	12	37	32	3	70	25	3	0
Labrador (Makkovik)	all ages	open water	1979	1	94	19	11	0	91	31	3	0
Narwhal												
Pond Inlet (ice edge)	all ages	haul out	1978	0	0	201	46	3	209	41	0	0
Pond Inlet (Kounuk + village)	all ages	open water	1978	0	1	76	29	0	75	23	8	0
Pond Inlet (ice edge)	all ages	haul out	1979	8	46	162	30	5	194	52	3	2
Harp seal												
Grise Fiord	immature	open water	1978	38	44	27	16	0	125	0	0	0
Grise Fiord	adult	open water	1978	7	35	71	16	0	129	0	0	0
Grise Fiord	adult	open water	1979	30	30	53	10	2	123	2	0	0
Pond Inlet (Kounuk + village)	immature	open water	1978	3	71	42	17	2	134	1	0	0
Pond Inlet (Kounuk + village)	adult	open water	1978	8	44	63	16	3	134	0	0	0

[a] Seasons are defined in Results section.

Table 3-4. Readability and abrasion values for Arctic cod otoliths from northern fulmar and thick-billed murre stomachs.

			Readability					Abrasion			
Location	Month(s)	Year	0	1	2	3	4	1	2	3	4
Northern fulmar											
Lancaster Sound	Jul-Sep	1976	4	0	18	9	0	24	7	0	0
Lancaster Sound—Northwest Baffin Bay	Jul-Sep	1978	0	1	8	20	8	4	23	10	0
Thick-billed murre											
Barrow Strait (ice edge)	Jun-Jul	1976	75	2	939	66	0	1043	6	33	0
Lancaster Sound	Jul-Sep	1976	9	4	18	11	2	34	4	6	0
Pond Inlet (ice edge)	Jun-Jul	1978	38	17	491	70	5	474	38	109	0
Lancaster Sound—Northwest Baffin Bay	Jul-Sep	1978	0	182	152	33	0	319	38	10	0
Pond Inlet (ice edge)	Jun	1979	16	0	151	19	0	160	11	15	0
Lancaster Sound—Northwest Baffin Bay	Jul-Sep	1979	4	8	36	11	3	18	42	2	0

APPENDIX 4: AGES, LENGTHS AND FREQUENCY DISTRIBUTIONS OF OTOLITHS TAKEN FROM WHOLE ARCTIC COD

Table 4-1. Age-frequency distribution for Arctic cod otoliths taken from whole fish.

COLLECTION	DATE(S) COLLECTED	AGE			AGE (YEARS)							
		MEAN	SD	NO.	0+	1+	2+	3+	4+	5+	6+	7+
Northwest Baffin												
Resolute Bay	1976	3.9	0.8	200	0	0	3	54	93	45	5	0
	1977	3.8	0.7	89	0	0	0	32	46	10	1	0
Beaufort Sea												
Simpson Lagoon	1977	2.1	1.3	189	12	50	74	28	15	8	1	1
	1978	2.8	1.1	142	0	12	54	46	21	5	3	1
	1979	1.9	0.8	61	3	10	37	10	1	0	0	0
Pond Inlet												
Button Point	1978	2.2	0.8	34	0	6	18	7	3	0	0	0
Tremblay Sound	1978	1.4	0.5	46	0	27	19	0	0	0	0	0
Ice edge	1979	2.3	0.8	91	0	14	41	33	1	2	0	0
Chukchi Sea												
Kasegaluk	1983	2.9	1.2	82	0	5	36	12	21	8	0	0

Table 4-2. Otolith ages and lengths (mm) and corresponding fish (fork) lengths (mm) for Arctic cod collected at Simpson Lagoon, Beaufort Sea, 977.

SAM	OTOLITH		FORK	SAM	OTOLITH		FORK
#	AGE	LENGTH	LENGTH	#	AGE	LENGTH	LENGTH
6095	3	6.4	172	6140	2	3.5	87
6096	2	3.3	81	6141	1	2	63
6097	2	3.7	94	6142	1	2.9	86
6098	2	3.3	89	6143	2	3.7	97
6099	2	3.3	81	6145	1	3	85
6100	1	2.9	71	6146	2	3.5	86
6101	2	3.7	92	6147	2	2.7	74
6102	2	3.7	91	6148	5	7.7	171
6103	5	7.7	183	6149	5	8.3	189
6104	5	7.9	180	6150	1	2.4	72
6105	1	2.9	78	6151	1	2.3	63
6106	1	3.5	87	6152	1	2.2	63
6107	0	2.4	65	6153	4	7.3	193
6108	1	2	67	6154	5	7.9	186
6109	0	2	56	6155	4	7.6	176
6110	2	3.3	84	6156	3	6.5	165
6111	2	3.2	85	6157	4	6.3	156
6112	4	6.9	171	6158	4	6.2	162
6113	2	4.1	110	6159	2	3.1	75
6114	2	2.9	68	6160	1	2.8	84
6115	2	3.3	81	6161	2	3.5	88
6116	0	2.4	71	6162	2	4.1	105
6117	2	3.7	108	6163	2	4.3	104
6118	2	3.4	83	6164	2	3.1	80
6119	3	6.5	155	6165	3	5.3	122
6120	7	10.8	251	6166	2	4	100
6121	0	1.7	54	6167	3	7	184
6122	2	3.6	59	6168	4	6.2	150
6123	1	2.1	87	6169	4	7.2	150
6124	2	3.3	84	6170	4	7.9	150
6125	1	2.8	72	6171	5	9.4	160
6126	2	3.3	85	6172	2	5.9	160
6127	1	3	78	6173	4	6.4	169
6128	2	4.2	103	6174	2	3.6	86
6129	3	4.8	120	6175	2	3.7	105
6130	4	6.9	170	6176	1	2.7	72
6131	2	3.1	84	6177	2	3.5	86
6132	2	3.5	92	6178	2	4	94
6133	1	2.4	65	6179	2	2.9	73
6134	1	3.4	86	6180	2	3.7	93
6135	2	3.8	89	6181	3	7.2	176
6136	4	5.4	116	6182	2	4.2	113
6137	2	3.4	87	6183	2	3.2	79
6138	1	2.4	66	6184	2	3.4	93
6139	1	3.2	82	6185	2	3.2	147

Continued ...

Table 4-2. Continued.

SAM	OTOLITH		FORK	SAM	OTOLITH		FORK
#	AGE	LENGTH	LENGTH	#	AGE	LENGTH	LENGTH
6186	1	3.5	86	6232	1	2.9	76
6187	2	4	106	6233	2	5.1	137
6188	2	5.1	128	6234	3	5.8	143
6189	3	5.8	125	6235	3	5.3	137
6190	3	5.7	136	6236	5	7.3	180
6191	2	3.3	98	6237	3	5.9	141
6192	1	2	63	6238	2	3.6	87
6193	1	2.5	76	6239	3	5.1	122
6195	1	3	80	6240	4	6.5	153
6196	3	5.5	129	6241	3	5	115
6197	1	2.8	81	6242	2	4.2	103
6198	3	6.1	141	6243	1	3.2	80
6199	3	6.5	154	6244	1	3.4	78
6200	2	3.2	76	6245	2	3.8	87
6201	2	4.2	110	6246	2	3.2	78
6202	2	4	96	6247	1	3.8	100
6203	2	3	75	6248	2	4.3	100
6204	2	3.3	84	6249	2	3.9	93
6205	2	3.7	88	6250	4	6.3	139
6206	1	2.7	75	6251	4	7.2	178
6207	2	3.6	81	6252	1	3.3	84
6208	1	3	81	6253	1	2.5	73
6209	0	2.5	73	6254	2	3.2	81
6210	0	2.4	57	6255	3	5	121
6211	2	3	78	6256	3	4.6	112
6212	0	2	63	6257	2	3.7	91
6213	1	2.8	79	6258	1	2.8	69
6214	0	2	65	6259	1	3.4	80
6215	0	2.6	78	6260	2	4.7	115
6216	2	3.7	93	6261	3	5.8	138
6217	1	3.1	82	6262	1	3.7	89
6218	1	3.5	91	6263	1	2.8	74
6219	1	2.6	74	6264	2	3.8	104
6220	1	3	85	6265	1	2	59
6221	1	2.9	81	6266	2	4.6	115
6222	1	2.8	77	6267	0	1.8	59
6223	1	3.5	96	6268	5	7.8	169
6224	1	2.4	70	6269	3	6	152
6225	2	3.3	90	6270	3	6.4	156
6226	1	3.2	89	6271	3	5.4	131
6227	2	3.6	80	6272	2	4.9	123
6228	3	4.4	109	6273	4	7.4	170
6229	1	3.3	88	6274	6	9.2	221
6230	3	7.1	182	6275	2	4.3	110
6231	1	3.4	89	6276	0	1.8	59

Continued ...

Table 4-2. Concluded.

SAM	OTOLITH		FORK	SAM	OTOLITH		FORK
#	AGE	LENGTH	LENGTH	#	AGE	LENGTH	LENGTH
6277	2	3.5	85	6282	2	2.9	79
6278	2	3.9	93	6283	0	2.1	74
6279	3	4.9	122	6285	1	2.3	67
6280	3	6.9	158	6286	2	3.3	84
6281	3	6.3	168				

Table 4-3. Otolith ages and lengths (mm) and corresponding fish (fork) lengths (mm) for Arctic cod collected at Simpson Lagoon, Beaufort Sea, 1978.

SAM	OTOLITH		FORK
#	AGE	LENGTH	LENGTH
6288	4	7.4	186
6289	3	6	145
6290	5	7.6	200
6291	3	6.7	159
6292	3	7	174
6293	3	6.8	170
6294	3	6.4	171
6295	2	3	73
6296	4	7.5	192
6297	2	3.2	80
6298	2	4	98
6299	2	3.8	102
6300	5	7.4	163
6301	2	3.3	78
6302	2	3.2	76
6303	2	3.6	90
6304	4	7.1	182
6305	2	3.1	77
6306	2	3.3	80
6307	4	6.2	145
6308	3	6.6	162
6309	4	7	165
6310	7	8.7	198
6311	4	7.4	182
6312	1	3.4	85
6313	2	4.1	101
6314	1	3.6	88
6315	2	4.2	92
6316	2	4.7	121
6317	2	2.4	64
6318	2	3.9	101
6319	4	6.6	181
6320	6	8.7	189
6321	2	3.5	85
6322	5	7.8	198
6323	3	6.8	168
6324	4	7.4	174
6325	2	4.4	110
6326	3	4.7	117
6327	2	5.9	145
6328	3	6.3	160
6329	3	5.8	148
6330	3	6.5	163
6331	3	7	170
6332	3	6.4	162
6333	3	6.7	155
6334	6	9.7	224
6335	2	3.2	77
6336	2	4.2	100
6337	2	3.6	94
6338	2	3	73
6339	3	6.6	158
6340	3	6.4	161
6341	2	5.8	159
6342	4	7.3	174
6343	3	6.8	162
6344	3	6.2	154
6345	4	6.8	224
6346	5	9.1	174
6347	2	3.6	92
6348	2	3.7	94
6349	1	3.8	103
6350	2	3.8	94
6351	2	3.9	101
6352	4	6.9	161
6353	2	3.5	89
6354	3	6.7	167
6355	4	7.5	171
6356	3	6.7	164
6357	1	2.2	65
6358	1	2.9	69
6359	2	3.1	78
6360	2	3	82
6361	2	3	74
6362	2	3.5	83
6363	1	2.6	68
6364	2	2.8	136
6365	3	5.6	126
6366	3	5.3	125
6367	3	4.9	114
6368	2	4.5	79
6369	1	3	89
6370	2	3.5	101
6371	2	4	70
6372	4	7.2	178
6373	5	10.2	235
6374	2	4.3	116
6375	2	4.9	130
6376	4	6	158
6377	2	3.9	96

Continued ...

Table 4-3. Concluded.

SAM	OTOLITH		FORK	SAM	OTOLITH		FORK
#	AGE	LENGTH	LENGTH	#	AGE	LENGTH	LENGTH
6378	3	6.5	156	6407	3	6.5	182
6379	2	4.4	114	6408	3	6.5	162
6380	1	4.2	107	6409	3	6.7	159
6381	4	6.7	170	6410	3	6.6	167
6382	2	4.5	108	6411	3	6.8	168
6383	2	4.8	120	6412	3	6.9	166
6384	2	5.2	122	6413	3	6.3	150
6385	3	6.7	177	6414	2	4.2	113
6386	2	4.4	104	6415	3	6.5	167
6387	2	4.1	113	6416	1	4.2	111
6388	2	4.3	110	6417	2	4.6	114
6389	1	4.4	107	6418	3	6.4	159
6390	2	4	110	6419	3	7.2	178
6391	3	6.4	166	6420	3	6	160
6392	3	6.3	170	6421	1	4.3	103
6393	4	8.6	203	6422	2	4.7	120
6394	3	7.3	196	6423	2	3.9	105
6395	4	7.8	169	6424	1	4.2	109
6396	3	7.3	194	6425	4	7.4	194
6397	4	7.3	174	6427	3	7.2	176
6398	3	5.9	145	6428	3	6.3	158
6399	3	6.1	142	6429	2	4.3	106
6401	4	6.7	170	6430	2	4.2	105
6402	3	7.1	181	6431	2	4.5	111
6405	4	8.1	187	6432	2	4.1	107
6406	3	5.8	160	6433	6	9.4	230

Table 4-4. Otolith ages and lengths (mm) and corresponding fish (fork) lengths (mm) for Arctic cod collected at Simpson Lagoon, Beaufort Sea, 1979.

SAM	OTOLITH		FORK	SAM	OTOLITH		FORK
#	AGE	LENGTH	LENGTH	#	AGE	LENGTH	LENGTH
6434	1	3.5	85	6476	2	4.9	120
6435	2	4.9	117	6477	1	5.2	125
6436	3	6	141	6478	2	5.6	140
6437	1	4	100	6479	3	5.7	129
6438	1	3.1	81	6480	2	5.3	120
6439	2	3.2	80	6481	2	4.7	110
6440	1	2.1	60	6482	2	5.3	129
6443	0	1.8	54	6483	1	2.5	65
6444	0	2	60	6484	2	5.9	130
6446	2	3.4	91	6485	2	6	153
6447	2	3.5	88	6486	2	5.4	129
6448	1	2.1	62	6487	1	3	82
6449	2	2.6	72	6488	3	4.9	120
6450	1	3.1	82	6489	2	4.7	106
6451	4	5.8	145	6490	2	4.2	94
6452	3	5.7	135	6491	3	5.4	139
6453	2	4.7	115	6492	2	4.9	121
6454	2	4.2	90	6493	2	5.1	119
6455	2	4	98	6494	3	5.4	142
6456	3	4.8	117	6495	2	4.7	112
6457	2	4.3	105	6496	2	5.1	130
6458	2	4.4	110	6497	2	5.2	125
6459	2	4.1	100	6498	3	5.6	147
6460	2	5.2	125	6499	2	5.3	126
6461	2	4.3	110	6500	2	5.1	122
6462	2	5	125	6501	2	5.2	123
6463	2	5	120	6502	2	5.3	126
6472	1	2.8	75	6503	3	5.3	134
6473	3	4.5	110	6504	2	6.1	132
6474	2	4.5	110	6505	0	3	76
6475	2	4.7	110				

Table 4-5. Otolith ages and lengths (mm) and corresponding fish (fork) lengths (mm) for Arctic cod collected at Kasegaluk, Chukchi Sea, 1983.

SAM	OTOLITH		FORK	SAM	OTOLITH		FORK
#	AGE	LENGTH	LENGTH	#	AGE	LENGTH	LENGTH
6506	5	7.1	160	6548	4	8.3	203
6507	3	6.2	132	6549	5	9	222
6508	1	4	99	6550	4	6.6	152
6509	4	6.5	149	6551	4	5.9	134
6510	2	4	96	6552	3	3.7	91
6511	3	5.5	130	6553	2	2.6	71
6512	2	5.1	117	6554	3	6.2	140
6513	4	7	158	6555	2	4.9	123
6514	3	7.1	169	6556	3	3.5	81
6515	4	5.9	135	6557	2	3.8	94
6516	3	3.8	97	6558	2	3.4	88
6517	4	6.5	151	6559	2	3.6	83
6518	2	3.2	95	6560	3	6	185
6519	4	6.7	158	6561	2	2.5	68
6520	2	2.8	74	6563	2	4	100
6521	2	2.7	75	6564	3	3.2	85
6522	3	5	92	6565	2	4.1	95
6523	2	2.8	74	6566	4	6.4	146
6524	3	3.8	88	6567	2	3.2	75
6525	2	3.6	92	6568	5	7.3	164
6526	2	2.9	74	6569	4	7.1	175
6527	2	3.2	77	6570	4	7.9	185
6528	1	2.2	58	6571	2	6.1	145
6529	2	2.4	63	6572	5	7.6	165
6530	2	3.8	92	6573	4	6.8	150
6531	1	3.1	79	6574	4	6.5	147
6532	4	6.6	157	6575	4	7	170
6533	2	3	72	6576	4	7.3	164
6534	2	2.5	65	6577	4	7.4	168
6535	5	8.1	186	6578	3	4.5	110
6536	4	6	143	6580	2	3	82
6537	2	2	60	6581	2	3.6	88
6539	2	2.7	71	6582	2	2.9	74
6540	4	7.2	159	6583	2	3	74
6541	2	3	76	6584	2	3.1	78
6542	5	8	201	6585	4	6.1	135
6543	5	7.7	195	6586	2	3.9	93
6544	5	7.2	175	6587	2	3.1	78
6545	2	2.9	75	6588	1	1.8	52
6546	4	7.4	185	6589	2	4.1	98
6547	2	2.3	62	6590	1	2.3	62

Table 4-6. Otolith ages and lengths (mm) and corresponding fish (fork) lengths (mm) for Arctic cod collected at Resolute Bay, August 1976.

SAM	OTOLITH		FORK	SAM	OTOLITH		FORK
#	AGE	LENGTH	LENGTH	#	AGE	LENGTH	LENGTH
5191	3	6.3	174	5437	3	5.7	151
5228	4	7.8	204	5439	5	6.3	160
5237	5	6.9	177	5441	4	6.2	162
5239	4	6.3	165	5443	4	7.1	157
5243	4	6.4	162	5448	4	6.9	184
5256	3	5.8	143	5449	4	8	170
5264	3	6.4	161	5452	3	6	159
5270	2	5.4	128	5457	4	7	177
5275	5	7.5	178	5460	3	7	180
5279	3	5.6	142	5471	3	5.9	152
5285	3	5.7	142	5472	5	6.7	161
5288	3	5.6	137	5476	4	6.9	157
5297	4	7.2	161	5478	4	6.4	175
5299	4	5.6	130	5492	4	6.9	157
5300	4	6.8	161	5500	4	7.3	160
5307	4	6.4	164	5507	3	6.2	165
5308	4	6.3	146	5515	4	7	163
5309	4	5.8	151	5533	4	6.3	162
5313	3	6.4	155	5537	3	6.9	165
5320	5	6.9	183	5561	5	7.5	192
5321	5	7	178	5567	4	7.4	184
5323	3	6.4	169	5572	4	6.1	163
5324	3	7.1	182	5576	4	6.4	159
5330	4	6.7	137	5578	3	6.1	158
5335	4	6.1	147	5581	4	6.9	171
5339	5	6.9	170	5583	4	7.1	176
5342	4	5.8	139	5584	3	6.9	175
5346	4	6.7	175	5589	5	5.6	139
5349	5	6.8	158	5595	3	6.1	145
5352	5	6.6	165	5598	3	5.2	129
5353	5	6.4	163	5603	5	8.1	188
5359	4	6.3	159	5608	4	5.5	133
5379	4	6.9	163	5609	4	6.2	148
5380	3	5.2	127	5619	4	5.7	140
5382	6	6.3	165	5634	4	6.9	171
5389	5	6.8	163	5636	4	6.1	164
5390	4	6.8	184	5637	4	6.4	155
5391	5	6	146	5638	5	6.5	158
5398	3	7.2	188	5644	5	6.2	165
5399	5	5.6	148	5652	5	7.7	176
5406	3	6.2	152	5653	3	5.5	147
5411	4	7.6	211	5655	6	6.6	148
5418	4	5.6	141	5670	4	6.9	171
5422	5	7.3	175	5671	4	7.5	179
5425	4	7.3	188	5674	3	6.2	168

Continued ...

Table 4-6. Concluded.

SAM	OTOLITH		FORK	SAM	OTOLITH		FORK
#	AGE	LENGTH	LENGTH	#	AGE	LENGTH	LENGTH
5681	3	6	161	5747	4	6.2	149
5707	3	5.9	147	5748	3	7.2	167
5721	3	6.6	156	5753	5	6.6	148
5726	4	6.6	171	5755	5	6.1	149
5728	3	5.3	134	5774	3	6.1	168

Table 4-7. Otolith ages and lengths (mm) and corresponding fish (fork) lengths (mm) for Arctic cod collected at Resolute Bay, September 1976.

SAM	OTOLITH		FORK	SAM	OTOLITH		FORK
#	AGE	LENGTH	LENGTH	#	AGE	LENGTH	LENGTH
5787	4	6.4	167	5872	4	5.4	139
5790	4	7.9	183	5873	3	5.7	137
5792	4	7.4	161	5876	3	5.8	133
5798	5	7.1	159	5879	4	6.9	165
5801	4	7.5	153	5880	3	6.7	165
5802	4	6.7	138	5881	3	6.7	166
5805	5	6.6	171	5882	3	5.9	144
5807	5	6.7	159	5883	4	6.9	161
5808	4	6.1	175	5884	3	6.3	167
5810	5	7.7	201	5886	4	7.3	181
5811	5	6.9	156	5889	4	6.7	162
5812	5	8.9	235	5890	3	6.4	156
5813	4	8.2	195	5894	4	5.7	145
5814	4	7.7	177	5895	5	7	191
5816	5	8.3	185	5898	3	6.2	160
5817	5	8.6	199	5899	5	7.3	180
5819	4	7.7	178	5902	3	6.4	157
5820	5	8.2	205	5905	4	6.5	156
5822	6	9.4	210	5907	4	5.7	147
5823	4	7.1	165	5909	3	5.8	141
5824	4	6.5	162	5910	3	5.2	131
5825	5	7.7	187	5912	5	6.8	162
5826	5	6.8	168	5913	4	7.3	159
5829	4	5.6	138	5914	4	6.4	145
5830	6	8.2	200	5915	5	7.2	169
5831	4	7	161	5916	4	6.6	166
5836	4	7.4	185	5917	3	6.9	163
5837	3	7	173	5920	3	5	131
5842	3	7.1	177	5927	4	6.5	161
5843	4	7	172	5928	4	6.8	176
5844	4	7.1	171	5929	4	7.1	178
5846	5	8.5	205	5932	4	7.6	184
5847	6	8.5	233	5934	5	7	177
5848	4	6.5	167	5939	5	8.9	239
5850	3	7.2	172	5940	5	8.9	220
5853	5	8.2	192	5943	5	6.9	170
5854	5	8.3	218	5945	3	5.4	130
5855	4	6.5	162	5947	4	6.7	155
5858	4	6.6	180	5949	5	6.7	157
5861	3	6.5	161	5950	4	6.9	175
5863	3	6.9	153	5951	4	6.5	155
5864	4	7.6	181	5952	3	5.5	133
5865	4	6.8	159	5953	4	5.8	156
5869	3	5.8	139	5955	4	7.3	177
5870	3	4.8	128	5956	4	7.2	174

Continued ...

Table 4-7. Concluded.

SAM	OTOLITH		FORK	SAM	OTOLITH		FORK
#	AGE	LENGTH	LENGTH	#	AGE	LENGTH	LENGTH
5957	4	6.4	163	5963	3	5.3	136
5958	4	6.6	165	5964	2	5.4	133
5959	4	7	168	5965	4	5.1	132
5960	4	6.4	161	5966	2	5.1	125
5962	3	5.1	122	5938	4	9.2	237

Table 4-8. Otolith ages and lengths (mm) and corresponding fish (fork) lengths (mm) for Arctic cod collected at Resolute Bay, 1977.

SAM	OTOLITH		FORK	SAM	OTOLITH		FORK
#	AGE	LENGTH	LENGTH	#	AGE	LENGTH	LENGTH
5000	5	9.3	246	5045	3	6.6	171
5001	5	7.8	207	5046	4	6.5	165
5002	5	9.6	246	5047	4	7.5	190
5003	4	9.7	225	5048	3	6.6	179
5004	4	9.3	252	5050	3	7.2	173
5005	4	9	226	5051	4	7.5	176
5006	5	9.6	235	5052	4	7.7	200
5007	4	7.4	177	5053	3	6.7	177
5008	4	7.9	171	5054	3	7.3	170
5009	3	7.5	177	5055	3	7.1	185
5010	3	7.1	176	5056	4	7.3	192
5011	3	7	179	5057	3	7.2	174
5912	3	6.8	164	5058	4	7.2	179
5813	4	6.9	184	5059	4	7.4	171
5814	3	6.7	173	5060	3	6.7	173
5015	3	6.7	174	5061	3	7.1	161
5016	4	7.4	182	5062	3	6.6	167
5017	4	7.4	190	5063	4	7.3	177
5018	5	9.2	208	5064	5	8.5	212
5019	4	8	200	5065	4	8.5	209
5020	4	8.2	217	5066	4	7	191
5021	4	7.2	180	5067	5	9.1	213
5022	4	9.1	221	5068	4	7.8	198
5023	5	9.3	222	5069	4	7.4	175
5024	3	8.6	218	5070	3	6.4	168
5025	5	9.9	250	5071	4	8.8	195
5026	3	8.7	226	5072	3	7.3	178
5027	4	6.9	175	5073	4	7.5	110
5028	4	6.3	172	5074	4	7.3	184
5029	4	7.1	181	5075	4	7.6	177
5030	3	6.6	168	5076	3	7	176
5031	4	7.3	179	5077	4	6.6	165
5032	4	7.4	172	5078	4	8.7	239
5033	6	8.5	210	5079	4	9.6	233
5034	4	7.9	186	5080	4	8.1	212
5035	3	7	177	5081	5	8.8	210
5036	3	6.7	180	5082	3	5.7	139
5037	4	7.4	171	5083	3	7.7	200
5038	4	7.4	183	5084	4	6.7	178
5039	4	6.4	168	5085	3	6.7	165
5040	4	6.4	172	5086	3	6.6	167
5041	4	7.3	184	5087	4	7.1	180
5042	3	6.9	176	5088	4	7.3	183
5043	3	7.2	172	5089	3	6.5	192
5044	3	6.5	167				

Table 4-9. Otolith ages and lengths (mm) and corresponding fish (fork) lengths (mm) for Arctic cod collected at Button Point, Pond Inlet, 1978.

SAM	OTOLITH		FORK	SAM	OTOLITH		FORK
#	AGE	LENGTH	LENGTH	#	AGE	LENGTH	LENGTH
5967	2	2.7	68	5986	2	4.9	118
5968	1	2.8	73	5987	2	4.8	118
5969	1	2.5	71	5988	2	4.3	96
5970	1	2.8	74	5989	3	4.9	112
5971	1	2.5	67	5990	3	5	126
5972	1	2.7	65	5991	2	4.3	102
5973	1	2.5	69	5992	3	4.5	114
5974	2	4.9	115	5993	3	5.1	117
5975	2	5.1	120	5994	2	4.4	100
5976	4	5.1	122	5995	3	4.3	-999
5978	4	6.2	142	5996	2	4.5	108
5979	3	4.8	110	5997	2	4.3	111
5980	2	4.7	110	5998	2	4.2	102
5981	3	4.6	115	5999	2	4.5	106
5982	2	4.3	106	6000	2	4.3	107
5983	2	4.7	107	6001	2	4.8	103
5984	4	5.5	135	6002	3	4.2	99
5985	2	4.7	110				

Table 4-10. Otolith ages and lengths (mm) and corresponding fish (fork) lengths (mm) for Arctic cod collected at Tremblay Sound, Pond Inlet, 1978.

SAM	OTOLITH		FORK	SAM	OTOLITH		FORK
#	AGE	LENGTH	LENGTH	#	AGE	LENGTH	LENGTH
6003	2	3.2	88	6051	1	3	78
6004	2	3	82	6053	2	3.4	85
6005	1	3.6	92	6057	2	3.4	84
6006	1	3.1	79	6060	1	3.4	84
6007	1	3.1	78	6062	1	3.3	88
6008	1	3.6	87	6063	1	2.6	73
6009	2	3.4	82	6064	1	2.7	73
6017	1	3.3	87	6065	1	2.7	71
6019	1	3.2	87	6067	1	2.8	82
6024	1	3.4	86	6069	2	3	78
6025	1	3.1	84	6070	2	3.1	78
6027	1	4	100	6073	1	3.5	87
6028	2	3.4	87	6075	2	2.9	78
6030	1	2.9	83	6076	1	3.2	86
6031	2	3.6	97	6078	1	3.6	94
6035	2	3.6	89	6079	2	3.1	82
6037	1	2.8	72	6080	1	3	85
6039	1	3.1	82	6084	2	2.9	82
6042	2	3.6	88	6085	2	3.2	81
6043	2	3	78	6087	1	3.1	78
6044	1	2.9	82	6088	1	3	80
6048	1	2.5	76	6089	2	3.3	86
6050	2	3.3	82	6092	2	3.2	79

Table 4-11. Otolith ages and lengths (mm) and corresponding fish (fork) lengths (mm) for Arctic cod collected at Pond Inlet ice edge, 1979.

SAM	OTOLITH		FORK	SAM	OTOLITH		FORK
#	AGE	LENGTH	LENGTH	#	AGE	LENGTH	LENGTH
5091	2	3.5	88	5141	2	3.4	85
5092	2	3.8	-999	5142	1	2.1	61
5093	2	3.8	92	5143	2	4.4	99
5094	2	4.6	112	5144	3	3.9	89
5095	2	3.7	93	5145	1	1.8	90
5096	3	4.4	109	5146	3	5.5	133
5097	2	4	96	5147	3	5.2	113
5098	2	4.5	108	5148	3	5.3	123
5099	2	3.7	89	5149	1	1.5	54
5100	2	4.9	119	5150	3	4.2	98
5102	2	4.6	100	5151	2	3.8	90
5103	2	4.3	115	5152	3	5.1	115
5104	2	4	89	5153	1	1.8	58
5105	2	4	102	5155	3	4.6	55
5106	2	4.7	111	5156	3	4.9	120
5107	3	5.7	128	5157	2	3.5	86
5108	1	1.8	58	5158	2	4.5	112
5109	3	4.6	105	5159	2	3.8	95
5110	2	3.5	89	5161	3	4.9	107
5111	3	4.1	106	5162	3	4.8	112
5112	1	1.6	55	5163	3	5.1	124
5113	1	2	65	5164	5	7.9	192
5114	3	4.5	104	5165	3	5.1	123
5115	2	4.3	113	5166	1	2.2	64
5116	1	1.8	59	5167	2	3.7	85
5117	3	4.6	113	5168	4	5.7	136
5118	2	3	80	5169	2	5.1	120
5119	3	4.8	108	5170	2	4.5	109
5120	3	5	131	5171	2	4.4	102
5121	1	1.4	50	5172	2	5	121
5122	2	3.3	87	5173	2	3.8	98
5123	3	5.2	121	5175	2	4.7	123
5124	2	4	93	5176	3	4.4	107
5125	2	4.2	97	5177	3	4.5	102
5126	3	4.8	112	5178	1	2.2	61
5127	1	1.9	59	5179	3	5.2	124
5128	2	4.7	111	5180	4	5.8	-999
5129	3	6.2	150	5181	2	3.6	93
5130	3	5.9	149	5182	1	2.4	65
5131	3	5.5	123	5183	2	4.9	114
5132	2	4.9	108	5184	3	6	142
5133	3	5.2	122	5185	2	4	99
5134	2	3.7	89	5186	2	3.7	90
5135	1	1.7	58	5187	3	6	138
5138	2	3.7	89	5188	1	1.5	53
5139	2	4.5	104	5189	3	4	99
5140	5	9.7	222	5190	3	4.9	112

APPENDIX 5: METAZOAN PARASITES OF ARCTIC COD

Arctic cod examined for metazoan parasites were collected from Resolute Bay (18 July 1976, n = 7) and Allen Bay (6 August 1976, n = 15), Cornwallis Island, N.W.T. Mean fork length of specimens was 176 mm with a range of 155-220 mm. Specimens were frozen within 36 h of capture and individuals were thawed immediately before examination.

METHODS

Necropsies were performed with a dissecting microscope at magnifications up to 30X. The following tissues and organs were examined microscopically: external body surface, fins, nasal cavities, cephalic mucous canals, eyes, gills, heart, buccal cavity, esophagus, stomach, pyloric caeca, intestinal tract, mesenteries, gall bladder, urinary bladder, liver, swim bladder, spleen, kidneys, gonads and musculature of the body. Musculature was sliced into thin (3-4 mm) sections for viewing. Other tissues and contents of the alimentary canal were teased apart in dishes containing saline solution. Most of the resultant mixture was then decanted after settling had occurred. If the remaining mixture was too cloudy for microscopic viewing, additional saline was added and again decanted. Depending on the number of parasites found, individual necropsies consumed from 2-6 h.

Host examinations were performed between 7 October 1976 and 7 February 1977. As parasites were recovered from the hosts, they were categorized into general taxonomic groupings (e.g., nematodes, trematodes) and into more specific taxa if possible (e.g., hemiurids, *Haemobaphes* sp.). During the nine years between parasite recovery and more detailed parasite identification in 1985, solutions in 30% of the vials containing parasites evaporated and rendered specimens useless for further taxonomic work. In computing infection rates, it was assumed that species or groups within these collections were distributed in the same manner as those found in well-preserved collections. For example, specimens in five of the 13 vials containing trematodes with small ventral suckers were desiccated. All specimens in the remaining eight vials were *Genolinea*. It is assumed that all desiccated specimens were of the same taxon. Due to the simplicity of the parasite fauna of Arctic cod from the 1976 collection, it is thought that relatively little information was lost by this procedure. Fortunately, many of the more difficult identifications were made before the specimens were archived in 1977.

Taxonomy of parasites follows that used by Margolis and Arthur (1979). General taxonomic references used were Wilson (1932) for copepods, Yorke and Maplestone (1969) and Chitwood and Chitwood (1974) for nematodes, Schell (1970) for trematodes, and Cheng (1964) for all groups.

Specific identifications of parasites, which would involve much time and effort, were not part of the study. Therefore, specimens were not stained or permanently mounted for microscopic examination. However, most nematodes were dissected to reveal esophageal and caecal structures.

RESULTS

Six types of metazoan parasites were recovered from Arctic cod, including nematodes, digenetic trematodes and copepods. Cestodes and acanthocephalens were absent. Table 5-1 lists incidences and intensities of infections.

Nematodes

Thynnascaris sp.: Only one type of nematode was found in Arctic cod. It occurred in an encysted state in mesenteries or on the surface of organs within the body cavity. Specimens were identified as being of the genus *Thynnascaris* due to the presence of three well-developed lips, an intestinal caecum, an esophageal ventriculus and an esophageal appendix. Three species of *Thynnascaris* have been reported from Atlantic fishes (Margolis and Arthur 1979). *Thynnascaris aduncum* is by far the most common, occurring in many fishes including Atlantic cod (*Gadus morhua*), Atlantic tomcod (*Microgadus tomcod*), and squirrel hake (*Merluccius* sp.) from waters off Labrador and Nova Scotia.

Infections of *Thynnascaris* sp. in Arctic cod were mild (Table 5-1). The highest single infection was six; commonly, only one worm was found per infected host. The life cycle of parasites of the family to which this species belongs is complex. Eggs of the parasite are shed with feces of the host. The eggs are eaten by the first intermediate host, usually a copepod, amphipod or jellyfish, and hatch within its intestine. The resultant larva burrows through the intestinal wall to encyst in the body cavity. If the first intermediate host is eaten by a fish, the nematode again burrows through the host's intestinal wall, re-encysts and develops into a more advanced larva. If the infected fish is then eaten by a mammal or, in some cases, another fish, the nematode matures and begins to shed eggs in the final host's intestine. The most obvious possible definitive host for this parasite in the Arctic is the ringed seal.

Trematodes

Only two types of trematodes were found in Arctic cod. Both were hemiurids inhabiting the intestinal tract.

Genolinea sp.: One trematode was referred to the genus *Genolinea* on the basis of presence of two compact vitelline glands and the position of the ventral sucker (in anterior half of body), and absence of a tail-like structure (ecsoma). *Genolinea laticauda* is a moderately common parasite of both Atlantic and Pacific marine fishes of Canada (Margolis and Arthur 1979). It is the only species of the genus reported from the alimentary canals of Atlantic fishes of Canada. The species appears to be primarily a parasite of flatfishes, being reported from winter flounder (*Pseudopleuronectes americanus*), witch flounder (*Glyptocephalus cynoglossus*) and Atlantic halibut (*Hippoglossus hippoglossus*) but not from Atlantic cod. The presence of *Genolinea* in Arctic cod is therefore unusual and more detailed taxonomic effort is warranted to confirm the present tentative identification.

Derogenes varicus: The other trematode was identified as being of the genus *Derogenes*, almost certainly *D. varicus*. Diagnostic characters of this genus are somewhat similar to those of *Genolinea*. One easily discernible difference is that the ventral sucker is larger and located more posteriorly in *Derogenes*. This species is found throughout the world's oceans in many hundreds of different species of fishes. It has been reported from a number of flatfishes, cods, herring and smelts from Atlantic Canada (Margolis and Arthur 1979).

Both of the above trematodes had moderately high infection rates (Table 5-1). Mean intensity of infection of *Derogenes* was substantially lower than that of *Genolinea*.

The life cycle of hemiurid trematodes is complex (Ginetsinskaya 1958). Adults are most commonly parasites of fishes, and sometimes amphibians. Eggs, shed with the feces of the host, contain larvae called miracidia. These hatch in sea water and burrow through the integument of the first intermediate host--a mollusc. They then develop into a more advanced stage and eventually cercariae are produced. These burrow through the skin of the intermediate host and become free swimming. Hemiurid cercariae have elongated bodies often terminating in long umbrella-like filaments that enable them to remain suspended for considerable periods. If cercariae are eaten by certain types of planktonic invertebrates, most commonly copepods, they burrow through this host's gut wall, encyst and develop into a more advanced larva called a metacercaria. The life cycle is completed when a fish eats the infected second intermediate host. Particulars of this life cycle have not been studied in the Arctic.

Copepods

Three types of copepods were found to parasitize Arctic cod--all with low infection rates and intensities (Table 5-1).

Haemobaphes sp.: Three specimens of *Haemobaphes* sp. were recovered from three Arctic cod. The specimens are referred to this genus on the basis of their unsegmented bodies with distinct head and neck, fused trunk and shape of egg sacs (regular spirals). Only one species of this genus, *H. cyclopterina* has been reported from the northwest Atlantic, mostly on bottom-dwelling fishes, sculpins, blennies and eelpouts (Margolis and Arthur 1979). This species was also reported from the Arctic sculpin (*Gymnocanthus tricuspis*) in the eastern Arctic by Wilson (1920, cited in Margolis and Arthur 1979). It is possible that the species parasitizing Arctic cod is *H. cyclopterina*, but more detailed examination of minute microscopic structures (and more specimens) would be required to confirm identifications.

Unlike many other parasites that appear to have little effect on their hosts, *Haemobaphes* infections are considered serious problems. The parasite is of substantial size (several centimetres) and infects the host by attaching to the gills, usually near their ventral juncture. The parasite's head and neck become elongated attachment/absorptive structures which grow into gill blood vessels and eventually protrude into the bulbus arteriosus.

The actual effects of *Haemobaphes* have been little studied, but information on another somewhat similar parasitic copepod, *Lernaeocera branchialis*, can be considered in order to gain an appreciation of potential effects. The latter parasite is common in certain stocks of Atlantic cod and Greenland cod (*Gadus ogac*) from Newfoundland and Labrador (Templeman et al. 1976). It too infects the host by absorptive growths into major gill and heart blood vessels (ventral aorta, bulbus arteriosus, branchial arteries). In addition to finding that *L. branchialis* was a useful indicator of inshore-offshore migrations of Atlantic cod in and near Newfoundland, Templeman et al. (1976) presented data which suggested that infection with the parasite delayed sexual maturity, and possibly decreased growth, of the host.

Low apparent intensities of infection are quite common for parasites of this type. Templeman et al. (1976) found most infected Atlantic cod to harbour one individual and never more than five. Polyanskii (1955) found infection of *L. branchialis* to be common in various gadids in the Barents Sea but never found more than three parasites on a particular host. Both Polyanskii (1955) and Bazikalova (1932, cited in Polyanskii 1955), noted emaciation in young infected fish. Unlike many other parasites, it appears that low intensities of infection with *Lernaeocera* sp. can have marked effects on the host. How such effects may apply to *Haemobaphes* sp. and Arctic cod is, of course, unknown. However, one hypothesis that can be raised is that high intensities of infection are lethal to the host. Such infections are unreported since mortality due to parasitism is difficult to detect.

Clavella sp.: One parasitic copepod was found attached to the skin near the base of the posterior dorsal fin. The specimen resembled species of the genus *Clavella* in that the second maxillae were entirely fused and extremely short, a bulla was the attachment organ, and the head was elongated and distinct from the trunk. *Clavella adunca* has been reported from Atlantic cod, haddock (*Melanogrammus aeglefinus*) and pollock (*Pollachius virens*) from eastern Canada, but *C. adunca* most commonly attaches itself to gills or inner surfaces of the gill cavity. Different species of *Clavella* are quite specific and selective as to site of attachment (e.g., *C. parva*--fin rays of many different types of fishes; *C. stellata*--skin near pelvic and pectoral fins of European hake). For this reason and the fact that no species of Clavella that attaches itself to the skin of the host has been reported from eastern Arctic or northwestern Atlantic, the specimen under consideration may not be C. adunca and possibly has not previously been reported in Canadian fishes. Considerable additional taxonomic effort and, possibly, specimens would be necessary to further investigate this parasite.

Clavella (?): One copepod parasite, in extremely poor condition, was found attached to a ray of the pectoral fin. The only common copepod parasites that attach to fin rays are of the genus Clavella and it is only on this basis that we suspect that the specimen from Arctic cod is of that genus. Additional specimens in good condition are needed.

DISCUSSION

On the whole, the metazoan parasite fauna of the Arctic cod that were examined was quite simple, consisting of possibly six species (one nematode, two digenetic trematodes and three copepods). Undoubtedly, additional parasites would be found with the examination of more hosts, especially if collected from different geographical areas. However, numbers of parasite species might still be low. For example, Margolis and Arthur (1979) list about 20 distinct parasites from Atlantic cod off the Canadian east coast. Numbers of species of many types of plants and animals decrease in the Arctic in comparison to more temperate regions. This may well apply to parasites, but comprehensive studies to support this general concept are non-existent.

Of interest is that the well known "cod worm", Phocanema decipiens, was not recovered from Arctic cod collected near Cornwallis Island. Adults of this parasite are very common in the alimentary canals of various seals. Larvae are common in the flesh and body cavity of a number of different species of Atlantic fishes off the Canadian east coast (Margolis and Arthur 1979).

Also of interest are the copepods found on Arctic cod. At least three types are now known to infect Arctic cod, one of which (Haemobaphes sp.) has the potential to affect the host seriously. Lernaeocera branchialis is similar to Haemobaphes in terms of potential serious effects. This latter species is a common parasite of Atlantic cod and Greenland cod, but it is as yet unknown in the Arctic.

Parasites have been successfully used as biological indicators to examine migration patterns of their hosts (Templeman et al. 1976); phylogenetic relationships (Sekerak 1975); differences in food habits between host populations or species (Margolis 1965); and habitat preference, behavioral differences among closely related host species, and discreteness of host populations (Delyamure 1955; Margolis 1965; Sekerak 1975).

Although the difficulties of collecting Arctic cod, together with the time-consuming nature of parasitological research, may preclude use of Arctic cod parasites to investigate host ecology, this avenue should not be completely ignored. Knowledge of the biology of Arctic cod predators could in some cases be obtained through knowledge of parasites transmitted by Arctic cod. For example, the present study suggests that larvae of the nematode parasite Phocanema decipiens may be rare or absent in Arctic cod. This parasite commonly matures in seals. Finley et al. (1983) described an offshore population of ringed seals in Baffin Bay on the basis of morphology, age structure, reproductive ecology and diet. They also presented limited data on nematodes, suggesting that offshore seals were infected with Phocanema (= Terranova in Finley et al. 1983) and inshore specimens with Thynnascaris (= Contracaecum in Finley et al. 1983). The present study found Thynnascaris to be the common nematode larvae of Arctic cod. The presence of Thynnascaris in ringed seal stomachs may thus be a good indication of previous consumption of Arctic cod.

More Arctic cod specimens and further taxonomic efforts would be needed to explore the full potential of using parasites to study Arctic cod biology and, in some cases, the biology of Arctic cod predators. Depending upon specific objectives, all types of parasites need not be considered. In general, the trematodes found in this study are rather cosmopolitan, and infect many different types of fishes. Thus they are poor candidates for use as biological indicators. Some types of copepods are extremely host-specific. This may be true of copepods of Arctic cod. They might thus be used to explore distinctness of populations or stocks of Arctic cod. The larval nematode parasites that are likely to infect Arctic cod may also be advantageous to study, since information might be gained on Arctic cod and their marine mammal predators if studies were so directed.

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Table 5-1. Metazoan parasites of Arctic cod (n = 22) from Resolute Bay and Allen Bay, Cornwallis Island, N.W.T., July-August 1976.

			Intensity of infection		
Parasite	Location in host	% infected	mean	maximum	Comments
Nematodes					
Thynnascaris sp.	Mesenteries in body cavity	82	2.06	6	All specimens larvae. Likely T. aduncum.
Trematodes					
Genolinea sp.	Stomach, caeca, intestine	68	12.3	23	
Derogenes varicus?	Stomach	72	3.8	10	Specimens also found in buccal cavity and on gill, presumably due to movement after host death.
Copepods					
Haemobaphes sp.	Gills	14	1.0	1	
Clavella?	Fin ray	5	1.0	1	Single specimen in very poor condition.
Clavella sp.	Skin	5	1.0	1	Attached near base of posterior dorsal fin.

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