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Size, Age and Diet of Polar Cod, *Boreogadus saida* (Lepechin 1773), in Ice Covered Waters

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Summary. Polar cod (*Boreogadus saida*) associated with drifting sea-ice were collected in the western Barents sea and north of Svalbard with dip-nets while SCUBA-diving in 1986 and 1987. Length-frequency measurements and otolith-readings suggested that the specimens were either one or two years old. The diet of fish from the western Barents sea (first-year ice) consisted mainly of copepods (*Calanus finmarchicus, Calanus glacialis*) and the hyperiid amphipod *Parathemisto libellula*. Fish collected north of the Svalbard archipelago (multi-year ice) had a more diverse diet, in which *P. libellula* and the sympagic amphipod *Apherusa glacialis* contributed more to the total diet biomass than copepods.

Introduction

The circumpolar polar cod (*Boreogadus saida*) is distributed in arctic waters with and without drifting sea-ice (Ponomarenko 1968). It is probably one of the most abundant fishes of the Arctic (Moskalenko 1964; Ponomarenko 1968; Falk-Petersen et al. 1986), and is frequently reported as an important food item and major fraction in the diet for a variety of marine birds, marine mammals and fish in the Arctic (e.g., Klumov 1937; Andriyashev 1954; Belopolskii 1957; Tomilin 1957; Baranenkova et al. 1964; Johnson et al. 1966; Quast 1974; Bain and Sekerak 1978; Lowry et al. 1979; Davis et al. 1980; Brown 1980; Lowry and Frost 1981; Bradstreet and Cross 1982; Haug and Gulliksen 1982; Sekerak 1982; Mehlum and Giertz 1984). It is generally accepted that polar cod function as a key link in the transport of energy from lower to higher trophic levels (Hognestad 1968; Rass 1968; Bain and Sekerak 1978; Bradstreet and Cross 1982; Craig et al. 1982).

The diet of polar cod living in close association with the ice undersurface is very little known (Bradstreet and Cross 1982), and the sparse information we have is mainly from fast ice above relatively shallow water. The data presented here are from waters covered with drift ice.

The sampling area was roughly divided in two main areas according to the age and history of the covering ice:

1. The sampling area north of Svalbard (NOS) is part of the Arctic ocean. It has usually a perennial cover of sea ice.
2. The sampling area in the western Barents sea (WBS). It has usually a seasonal sea ice cover, and is often almost free of ice by the end of the summer (Parkinson et al. 1987).

The Barents sea is partly blocked by several islands along its northern boundry reducing the flux of ice between the two areas. The perennial sea ice is known to harbour a unique sympagic fauna (Carey 1985). The differences in ice-conditions between the two sampling areas (NOS versus WBS) were therefore believed to influence food available for the polar cod. The main purpose of the present investigation was to collect information about the biology and diet of polar cod in sea ice, and especially to study if cod in different types of ice had different diets.

Material and Methods

The specimens were caught in 1986 and 1987 from 9 different localities in the western Barents sea (WBS) and north of the Svalbard archipelago (NOS) (Table 1). The localities in the ice were reached, either directly with the research vessel *Lance* (1986), the coast guard vessel *Nordkapp* (1987) or with helicopters from *Lance* (1986).

The age of the ice (first-year ice or multi-year ice) at the sampling localities (Table 1) was determined in the field, on the basis of visual observations and ice-charts. We use the designation first-year ice if most (> ca. 80%) of the ice was formed the preceding year, and the designation multi-year ice if most (> ca. 80%) of the ice has survived minimum one summer (melting period).

A total of 114 polar cod (Table 1) were collected individually with a dip-net mounted on a telescope pole while SCUBA-diving between and underneath ice-floes.

The stomach of the polar cod were immediately removed and preserved in 80% alcohol. Total length of all specimens were measured to nearest 0.1 cm. Sagittal otoliths were collected for later age-determinations. The remainder of the fish was frozen for weight-determinations on land.

Table 1. Sampling stations, sampling dates, localities, number of fish collected and type of ice at the localities. FYI = First-year ice; MYI = Multi-year ice; WBS = Western Barents sea; NOS = North of Svalbard

Stn	Date	Locality	Area	No. of fish	Type of ice
1986					
1	25 May	76°44'N 28°53'E	WBS	10	FYI
2	29 May	75°77'N 33°47'E	WBS	46	FYI
3	30 May	76°26'N 34°12'E	WBS	16	FYI
4	5 June	77°17'N 27°36'E	WBS	3	FYI
5	31 July	80°52'N 28°11'E	NOS	11	MYI
6	4 Aug	81°19'N 14°00'E	NOS	7	MYI
7	7 Aug	81°00'N 1°57'E	NOS	8	MYI
1987					
8	3 March	76°36'N 30°10'E	WBS	12	FYI
9	5 March	76°05'N 23°40'E	WBS	1	FYI

Table 2. Frequency of occurrence (%) of prey items in the stomachs of *Boreogadus saida*. WBS = Western Barents sea; NOS = North of Svalbard

No. of stomach/Prey items	1986		1987
	WBS	NOS	WBS
Empty stomachs	5.3	0	0
Gastropoda		3.0	7.7
Crustacea			
Ostracoda		15.4	0
Copepoda (Calanoida)	65.3	46.2	84.6
Amphipoda			
Parathemisto libellula	18.7	26.9	15.4
Apherusa glacialis	1.3	46.2	0
Onisimus spp.		26.9	0
Gammarus wilkitzkii		7.7	0
Decapoda			23.1
Larvacea		19.2	0
Chaetognatha	6.7	15.4	0

Table 3. Number of specimens recorded (n) and relative frequency of occurrence in percent (f) in the stomachs of *Boreogadus saida* from 1986. WBS = Western Barents sea; NOS = North of Svalbard

	WBS		NOS	
	n	f	n	f
Gastropoda	0		45	8.0
Crustacea				
Ostracoda	0		62	11.1
Copepoda (Calanoida)	2872	98.9	180	32.1
Amphipoda				
Parathemisto libellula	21	0.7	67	11.9
Apherusa glacialis	1	0.0	141	25.1
Onisimus spp.	0		27	4.8
Gammarus wilkitzkii	0		2	0.4
Larvacea			13	2.3
Chaetognatha	10	0.3	24	4.3

Table 4. The dry weight of each food category as a percentage of the total dry weight of stomach contents from 1986. WBS = Western Barents sea; NOS = North of Svalbard

Food category	WBS	NOS
Gastropoda		0.7
Crustacea		
Ostracoda		3.3
Copepoda (Calanoida)	74.6	3.3
Amphipoda	2.6	68.7
Parathemisto libellula	2.4	43.2
Apherusa glacialis	0.2	18.1
Onisimus spp.		7.1
Gammarus wilkitzkii		0.3
Larvacea		0.9
Chaetognatha	1.2	1.4
Unidentifiable material	21.7	21.7

Age determinations were performed by counting annular zones on the otoliths. The zones were cleared by soaking the otoliths in water a few hours, prior to examinations through transparent light in a binocular microscope.

Food items in the stomachs were identified to species level or nearest possible taxa. Dry weight determinations were performed after drying stomach food items and the remaining parts of the fish at 60 °C for ca. 24 h. Individual dry weights were thus calculated by including the weight of the dried otoliths.

Analysis of stomach content can be done using different methods. Accepted feeding indices are subject to various biases and shortcomings, due for instance to different size of food items. The results from the stomach analysis are therefore presented using the following parameters:

1. Frequency of occurrence (%) of empty stomachs and stomachs containing one or more individuals of each food category were recorded in order to give a crude qualitative picture of the food spectrum (Hyslop 1980) (see Table 2).
2. Relative frequency of occurrence was calculated as the fraction (by numbers) a given prey item constituted of all prey categories (see Table 3).
3. The total dry weight of each food category from each stomach was expressed as a percentage of total dry weight of stomach content, giving an indication of the relative importance of each food category (Eliassen and Jobling 1985) (see Table 4).

Results

Ice Conditions

There was a dominance of first-year ice at all WBS stations both in 1986 and 1987. The NOS stations were all in areas with multi-year ice (Table 1).

Habitat and Behaviour

The polar cod was very seldom observed in the open leads and channels between ice-floes; nor under ice with a flat surface without melting holes or crevices. Typical habitats were between sandwiched ice-floes (Fig. 1) or in melting holes and crevices of the ice. The fish actively sought a hiding-place when approached by a SCUBA-diver. Quite often the hiding-place was difficult to reach with the dip-

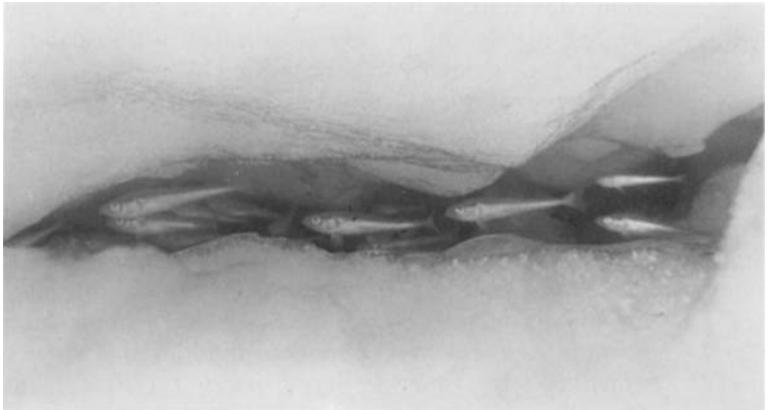

Fig. 1. Photograph of polar cod (*Boreogadus saida*) between sandwiched ice-floes

net on the telescope-pole, and a fish, feeling safe, seemed to be a calm observer to the diver's fishing-efforts.

The fish were usually observed in small schools below the ice-floes, but seemed to behave individually when approached by divers. For example, single fish often left the schools when approached, seeking 'better' hiding-places, and there seemed to be no urge for rejoining the school.

Age and Size

1986: The collected 101 specimens ranged in length from 59 to 168 mm. Specimens sampled in May – June from WBS stations ranged from 59 to 119 mm while specimens from NOS stations sampled in July – August ranged from 85 to 168 mm (Fig. 2). The results from the readings of otoliths suggest that all specimens belong to either year-class I or II (Fig. 3). Eighty percent of the specimens from WBS stations (in first-year ice) belong to year-class I while the corresponding number from NOS stations (in multi-year ice) is 38%.

The mean length of the youngest year class was 81.6 mm (SD = 9.3) in WBS and 102.0 mm (SD = 12.6) in NOS. The mean length of the oldest year class was 108.7 mm (SD = 9.1) in WBS ice and 125.3 mm (SD = 21.6) in NOS (Fig. 3).

1987: 12 of the 13 specimens collected were one year old and ranged in length from 64 to 96 mm; one two year old fish was 106 mm long.

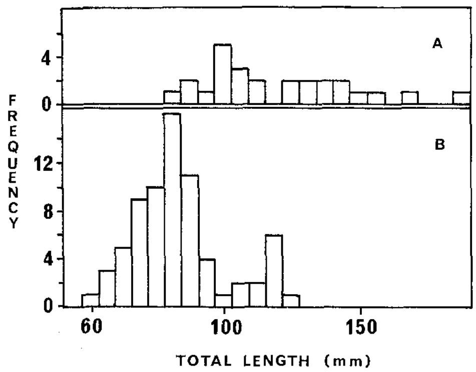

Fig. 2. Length distributions of polar cod caught north of Svalbard (*A*) in multi-year ice and in the western Barents sea (*B*) in first-year ice in 1986

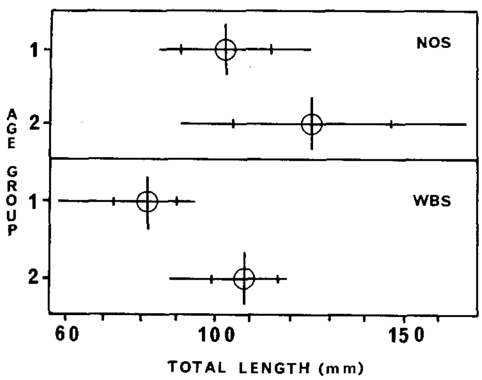

Fig. 3. Mean length at age of polar cod caught north of Svalbard (NOS), July – August 1986, in multi-year ice and in the western Barents sea (WBS), May–June 1986, in first-year ice, with range and standard deviations of the total lengths indicated

Diet

1986: 4.0% of the collected polar cod this year had empty stomachs, and all these individuals were recorded at WBS stations (Table 2).

Ten different invertebrate species (excluding endoparasites) belonging to four different major taxa (Gastropoda, Crustacea, Larvacea, Chaetognatha) were recorded in the stomachs of the collected polar cod. Crustacea was by far the most frequent group in fish from both areas (Table 2).

Larvaceans and gastropods were not recorded in fish from WBS (Table 2). Most frequent were copepods (mainly *Calanus finmarchicus* and *Calanus glacialis*) and the hyperiid amphipod *Parathemisto libellula* (Table 2). The stomach content was more diverse in fish caught NOS, and all ten different food item species were recorded in a material of 26 fish compared to five food item species in a material of 75 fish from WBS.

Copepods were most numerous (Table 3) and contributed most to the total dry weight of the stomach content (Table 4) from WBS fish. Other organisms seemed to have little importance. Crustaceans were still the most important group in the stomach contents of NOS fish (Tables 3 and 4). However, copepods were less numerous and contributed less to the total biomass than amphipods. The two most important amphipod species were *P. libellula* and *A. glacialis.*

Living polar cod were collected and kept in running seawater on deck. The fish were fed living copepods, *A. glacialis, Onisimus* spp. and *G. wilkitzkii.* Copepods, *A. glacialis* and *Onisimus* spp. were the preferred food items while *G. wilkitzkii* were not eaten even if it was the only prey available.

In both WBS and NOS samples there was about 20% (by weight) of unidentifiable material. This material mostly consisted of partly digested copepods which were difficult to separate and identify. The importance of copepods may therefore be somewhat higher than the numbers indicate.

1987: No fish with empty stomachs were collected, and copepods were the predominant stomach-content in all specimens (Table 2).

Discussion

The selection of habitat and the escape behaviour of polar cod is probably an adaptive escape reaction from predators. Polar cod is the main food item for many birds and seals in the ice, and the significance of hiding for individual survival is obvious.

All specimens of polar cod captured belonged to age-group I or II. 0-group and fish older than age-group II were not observed in situ nor collected in the simultaneous collections of invertebrate sympagic fauna (Lønne and Gulliksen, in preparation)

The lack of older individuals than year-class I and II can be explained by the behaviour of the fish; they descend to greater depths during spawning (Ponomarenko 1968). The lack of other year-classes than I and II support the view that spawned polar cod do not return to the surface.

There was a significant difference in the age structure of the samples from the two areas, with a larger proportion year-class I in first year-ice. This is probably controlled by the seasonality in the ice covering, forcing the fish to descend to deeper waters, or making them easier to catch by their predators. One should, however, bear in mind the limited number of fish in the samples when interpretating the data.

Falk-Petersen et al. (1986) gives a mean length of 9.8 cm for year class I and 12.9 cm for year class II based upon pooled data for material collected between 17 July and 4 August 1980. We obtained results quite similar to these. There are, however, differences between fish collected in WBS stations and fish from NOS stations. These differences are probably due more to different times of sampling than differences in growth.

There were marked differences in the diet of fish from WBS stations (first-year ice) compared to that of fish from NOS stations (multi-year ice). Fish from first-year ice fed merely on pelagic crustaceans with calanoid copepods as the most important food. This diet is quite similar to that often recorded in open waters. Hognestad (1968), for example, recorded a dominance of *Calanus finmarchicus* in the stomachs of polar cod from open waters in the Barents Sea.

The diet from multi-year ice consisted both of pelagic and sympagic organisms. The sympagic amphipods *Apherusa glacialis* and *Onisimus* spp. were significantly more common in fish from multi-year ice. *Parathemisto libellula* was also more common, but this is a species which is less sympagic than *Apherusa glacialis* and *Onisimus* spp. (Lønne and Gulliksen, in preparation). Sympagic fauna was also collected on the same cruises (Lønne and Gulliksen, in preparation), and it may be concluded that diet of the polar cod mainly reflects the fauna on the ice undersurface and in the immediate water masses, with one important exception: The sympagic amphipod *Gammarus wilkitzkii* was not a main food item for polar cod. This amphipod sometimes contributed more than 80% of the total biomass of sympagic fauna where the polar cod was collected, but only a few, small *G. wilkitzkii* were recorded in the polar cod stomachs. A quite similar observation was made by Barnard (1959) from Fletcher's ice island. Although *G. wilkitzkii* was the dominating amphipod in traps, the stomachs of collected polar cod were dominated by *A. glacialis.*

G. wilkitzkii grow larger (maximum size >ca. 35 mm) than *A. glacialis* (maximum size ca. 13 mm), but small *G. wilkitzkii* were also available on the ice undersurface. The avoidance of *G. wilkitzkii* is probably not only due to size, but also due to the 'spiny' morphology of this amphipod.

Generally, the diet of polar cod is reported to consist of crustaceans (most often amphipods and copepods) (see e.g., Bain and Sekerak 1978: Lowry and Frost 1981; Bradstreet and Cross 1982). There are, however, large variations in the results from investigation to investigation, and food availability within different habitats appears to play an important role in determining the species composition of the prey of polar cod. For example, polar cod collected from near-shore ice cracks have been shown to eat proportionally more epibenthic invertebrates than polar cod collected from open waters (Bain and Sekerak 1978).

The association of polar cod with ice and the abundance of polar cod in ice covered areas has been discussed in several publications (see e.g., Andriyashev 1970; Bain and Sekerak 1978), but no reliable density figures for polar cod under the ice is available. Density estimates based upon SCUBA-diving have been presented, but our experience is that different divers usually give very different estimates when working in the same area. The estimates are quite dependent upon the experience of the diver. Finding polar cod in the ice is a matter of learning where and how the polar cod hide in crevices, cracks and between sandwiched ice-floes.

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References

Andriyashev AP (1954) Fishes of the northern seas of the U.S.S.R. (transl. from Russian). Israel Program for Scientific Translations, Jerusalem 1964, 617 pp

Andriyashev AP (1970) Cryopelagic fishes of the Arctic and Antarctic and their significance in polar ecosystems. In: Holdgate MW (ed) Antarctic ecology, vol 1. Academic Press, New York, pp 294–303

Bain H, Sekerak AD (1978) Aspects of biology of Arctic cod, *Boreogadus saida*, in the Central Canadian Arctic. LGL, Ltd, Toronto, Ontario, 104 pp

Baranenkova AS, Ponomarenko VP, Khoklina NS (1964) Distribution, size and growth of larvae and fry of polar cod (*Boreogadus saida* Lepechin) in the Barents Sea. – Coun Meet Int Coun Explor Sea 1964 Gadoid Fish Committee (Mimeo) 96:1–15

Barnard JL (1959) Epipelagic and under-ice Amphipoda of the central Arctic Basin. Geophys Res Papers 63:115–152

Belopolskii LO (1957) Ecology of sea colony birds of the Barents Sea. Israel Program for Scientific Translations, Jerusalem 1961

Brown RGB (1980) Seabirds as marine animals. In: Burger et al. (eds) Behaviour of Marine Animals, vol 4. Plenum, New York, pp 1–39

Bradstreet MSW, Cross WE (1982) Trophic relationships at high arctic ice edges. Arctic 35:1–12

Carey AG (1985) Marine ice fauna: Arctic. In: Horner RA (ed) Sea ice biota. CRC Press, Florida, pp 173–203

Craig PC, Griffiths W, Haldorsen L, McElderry L (1982) Ecological studies of arctic cod (*Boreogadus saida*) in Beaufort sea coastal waters, Alaska. Can J Fish Aquat Sci 39:395–406

Davis RA, Finley KJ, Richardson WJ (1980) The present status and future management of arctic marine mammals in Canada. Science Advisory Board of the Northwest Territories. Rep no. 3. Department of Information, Government of the NWY, 93 pp

Eliassen J-E, Jobling M (1985) Food of the rougthead grenadier, *Macrourus berglax*, Lacepede in North Norwegian waters. J Fish Biol 26:367–376

Falk-Petersen I-B, Frivoll V, Gulliksen B, Haug T (1986) Occurrence and age/size relations of Polar cod, *Boreogadus saida* (Lepechin), in Spitsbergen coastal waters. Sarsia 71:235–245

Haug T, Gulliksen B (1982) Size, age, occurrence, growth and food of Greenland halibut, *Reinhardtius hippoglossoides* (Walbaum) in coastal waters of western Spitzbergen. Sarsia 68:293–297

Hognestad PT (1968) 1. Observations on Polar cod in the Barents sea. Rapp P-V Reun Cons Int Explor Mer 158:126–130

Hyslop EJ (1980) Stomach contents analysis – a review of methods and their application. J Fish Biol 17:411–429

Johnson ML, Fiscus CH, Ostenson BT, Barbour ML (1966) Marine mammals. In: Wilimovsky NJ. Wolfe NJ (eds) Environment of the Cape Thompson Region, Alaska. United States Atomic Energy Commission, Oak Ridge Tennessee, pp 897–924

Klumov SK (1937) Polar cod and their importance for certain life processes in the Arctic. (in Russian). Izv Akad Nauk SSSR, Ser Biol 1:175

Lowry LF, Frost KJ (1981) Distribution, growth, and foods of Arctic Cod (*Boreogadus saida*) in the Bering, Chukchi, and Beaufort Seas. Can Field-Nat 95:186–191

Lowry LF, Frost KJ, Burns JJ (1979) Potential resource competition in the southeastern Bering Sea: fisheries and phocid seals. Proc 29th Alaska Sci Conf. Fairbanks, 15–17 August 1978, pp 287–296

Mehlum F, Giertz I (1984) Feeding ecology of seabirds in the Svalbard area – a preliminary report. Nor Polarinst, Rapp Ser 16:1–41

Moskalenko BF (1964) On the biology of Arctic Cod, *Boreogadus saida* (Lepechin). Vopr Ikhtiol 4:32, 433–443

Parkinson CL, Comiso JC, Zwally HJ, Cavalieri DJ, Gloersen P (1987) Arctic sea ice, 1973–1976: Satellite passive-microwave observations. NASA, Scientific and Technical Information Branch, Washington DC

Ponomarenko VP (1968) Some data on the distribution and migrations of polar cod in the seas of the Soviet Arctic. Rapp P-V Reun Cons Perm Int Explor Mer 158:131–135

Quast JC (1974) Density distribution of juvenile arctic cod, *Boreogadus saida*, in the eastern Chukchi Sea in the fall of 1970. Fish Bull 72:1094–1105

Rass T (1968) Spawning and development of polar cod. Rapp P-V Reun Cons Perm Int Explor Mer 158:135–137

Sekerak AD (1982) Young-Of-the Year Cod (*Boreogadus*) in Lancaster Sound and Western Baffin Bay. Arctic 35:75–87

Tomilin AG (1957) Cetacea. In: Heptnes VG (ed) Mammals of the USSR and adjacent countries. Translated from Russian by Israel Program for Scientific Translations 1976