Distribution, Growth, and Foods of Arctic Cod (*Boreogadus saida*) in the Bering, Chukchi, and Beaufort Seas

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Arctic Cod (*Boreogadus saida*) are abundant and ecologically important in arctic and subarctic marine ecosystems. Based on otter trawl collections made in the northern Bering and northeastern Chukchi and Beaufort seas, Arctic Cod were most abundant in the northeastern Chukchi and western Beaufort seas. There was no relationship between water depth and abundance; however, in the Chukchi and Beaufort seas small fishes were more common in water less than 100 m deep. Annual growth increments appear to be quite variable which complicates interpretation of size at age data. Arctic Cod less than 4 yr were larger at a given age in the Bering Sea. In the Bering Sea gammarid amphipods were the main food with mysids, shrimps, and hyperiid amphipods also eaten. In the northeastern Chukchi and Beaufort seas, calanoid copepods were by far the predominant prey with other crustaceans eaten much less frequently. Arctic Cod appear to be a very adaptable species which may explain their overwhelming success in Arctic marine waters.

Key Words: *Boreogadus saida*, Arctic Cod, distribution, foods, growth, abundance.

Three species of gadid fishes are abundant and ecologically important in marine waters of western and northern Alaska. Walleye Pollock (*Theragra chalcogramma*) is the most abundant finfish in southern and central Bering Sea (Bakkala, R. G., and G. B. Smith 1978. Demersal fish resources of the eastern Bering Sea: spring 1976. Northwest and Alaska Fisheries Center Processed Report. 233 pp.). Saffron Cod (*Eleginus gracilis*) is the most abundant species during summer months in the northern Bering and southern Chukchi seas (Wolotira, R. J., J. M. Sample, and M. Morin, Jr. 1977. Demersal fish and shellfish resources of Norton Sound, the southeastern Chukchi Sea and adjacent waters in the baseline year 1976. Northwest and Alaska Fisheries Center Processed Report. 292 pp.). In truly arctic waters and in winter months in the northern Bering and southern Chukchi seas, Arctic Cod (*Boreogadus saida*) is by far the most abundant forage fish species (Moskalenko 1964; Ponomarenko 1968). In combination these species provide a large portion of the annual nutrition of most species of marine mammals in these areas (Klumov 1937; Tomilin 1957; Johnson et al. 1966; Lowry et al. 1979). Generally, a more diverse assemblage of forage fish species are available and utilized in the Bering than in the Chukchi and Beaufort seas. In the Beaufort Sea, Arctic Cod is virtually the only widely distributed and abundant forage fish species.

The biology of Walleye Pollock has been studied in detail because of its importance in commercial bottomfish catches. Less is known of the biology of Arctic and Saffron Cods although there have been several significant studies of Arctic Cod in the Barents Sea and in Siberian waters (Moskalenko 1964; Baranenkova et al. 1966; Hognestad 1968; Ponomarenko 1968; Rass 1968). In light of their ecological importance and pending developments which may affect marine systems, detailed information on the biology of Arctic and Saffron Cod in Alaskan waters is greatly needed. In this paper we present observations on the biology of Arctic Cod caught by bottom trawls in the Bering, Chukchi, and Beaufort seas.

Methods and Materials

Tows were made using a 5.8-m (19-ft) headrope semiballoon otter trawl with 3.2-cm (1.25-in.) stretch mesh webbing in the body and 0.6-cm (0.25-in.) stretch mesh liner in the cod end. In the northeastern Chukchi and Beaufort seas, 33 successful tows (10 min bottom time) were made during the period 2 August to 3 September 1977. This set of tows was broken down by three subareas: northeastern Chukchi Sea (west of Point Barrow), 10 tows; western Beaufort Sea (Point Barrow to Prudhoe Bay), 8 tows; central Beaufort Sea (east of Prudhoe Bay), 15 tows. In the northern Bering Sea 32 tows (20 min bottom time) were made between 27 May and 10 June 1978 (Figure 1). Arctic Cod were sorted from other components of the trawl catches. Fishes caught in the Bering Sea tows were immediately enumerated, weighed, and measured (fork length to the nearest millimetre), and otoliths and stomachs were removed. Stomachs were split open and the contents were washed into a petri dish where prey items were identified and separated by taxon. Components of the stomach contents were ranked according to their relative abundance, i.e., the most abundant prey was given a rank of 1, the second most abundant a rank of 2, and so on. Arctic Cod

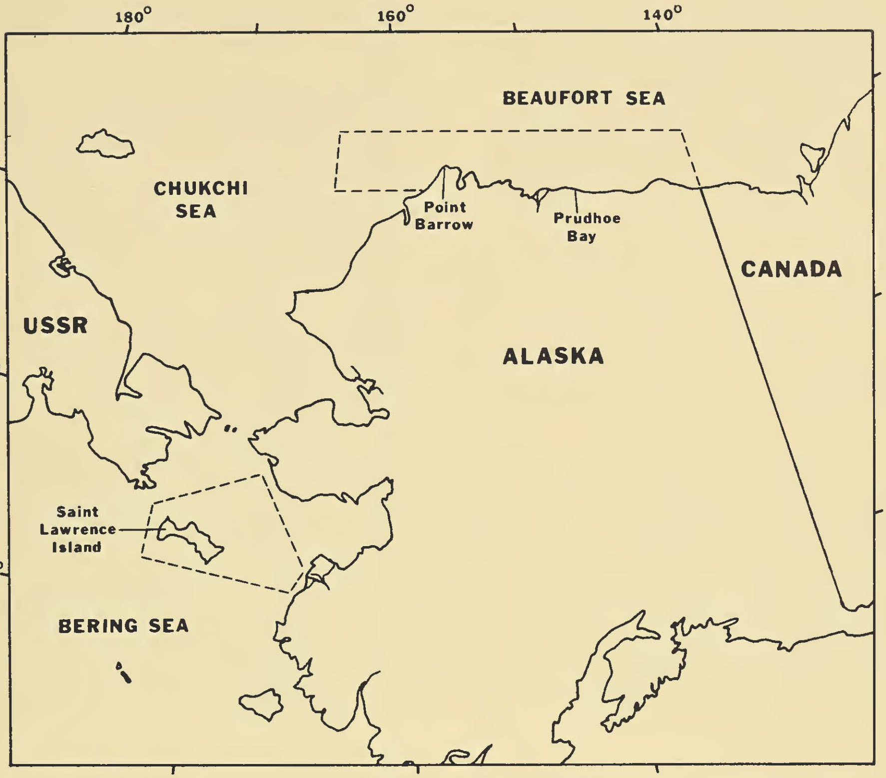

FIGURE 1. Map of Alaska showing the two regions (broken lines) where Arctic Cod were collected.

caught in the Chukchi and Beaufort seas were treated similarly except that fishes were preserved by injection of 10% formalin into the abdominal cavity and immersion in a 10% formalin-seawater solution. Fishes were weighed and measured and stomach contents were examined 3–6 wk later. For presentation of results, lengths of preserved fishes were corrected for shrinkage resulting from preservation by increasing measured length by 2.1% (Lowry and Frost, unpublished data based on 25 Arctic Cod measured before and after 3 wk preservation in 10% formalin). Ages of fishes were determined using annular rings in otoliths. The medial surface of each otolith was ground on a fine stone. The otoliths were then immersed in xylene and the rings counted using a binocular microscope and reflected light. In some otoliths, rings were more easily observed by examining a cross section. In such cases the otolith was broken transversely through the middle and the broken surface was polished, then examined under the microscope.

Results and Discussion

The overall distribution of Arctic Cod generally coincides with that of seasonal and multiyear sea ice (Andriyashev 1954; Ponomarenko 1968). With the exception of three tows in the Bering Sea, all our tows were made in or very near pack ice. In the Bering Sea, Arctic Cod were caught in three tows south of the ice; the most southerly occurrence was at 61°33′0″N, 174°30′48″W, about 300 km from the ice on 27 May 1978. This area had been ice-covered 3 wk previously. Arctic Cod are still widely distributed although not particularly abundant in the northern Bering Sea in late summer, long after the ice has gone (Wolotira et al. 1977, *op. cit.*).

In our samples, Arctic Cod were most widespread and abundant in the northeastern Chukchi and western Beaufort seas and least abundant in the northern Bering and central Beaufort seas (Table 1). This is perhaps due to many Arctic Cod from the northern Bering and southern Chukchi seas moving north with

TABLE 1—Occurrence and relative abundance of Arctic Cod in the study areas

Area	Number of tows	Tows with Arctic Cod (%)	No. of Arctic Cod per tow, mean (range)
Northern Bering Sea[1]	32	56.2	3.3 (0–37)
Northeastern Chukchi Sea[2]	10	100.0	10.3 (1–26)
Western Beaufort Sea[2]	8	100.0	7.8 (2–24)
Central Beaufort Sea[2]	15	66.7	1.9 (0–11)

[1]Bottom time 20 min.
[2]Bottom time 10 min.

the receding ice edge, and suggests that they do not penetrate far to the east in the Beaufort Sea. There was no obvious relationship between depth of water and catches of Arctic Cod. In the northeastern Chukchi and Beaufort seas, 26 tows were made in water 40–100 m deep while 8 tows were in waters 101–400 m deep. The mean number of Arctic Cod caught was 5.7 in shallow tows (range 0–26) and 5.5 in deeper tows (range 0–24). In the Bering Sea most tows were in waters less than 50 m deep and again there was no obvious relationship between abundance and water depth.

We casually examined the gonads of the larger Arctic Cod caught; in both sexes these were small, ranging in weight from 0.1 to 0.9 g, usually less than 3% of the total body weight of the fish. That is consistent with previous observations that gonadal development begins in September in preparation for spawning during winter months (Moskalenko 1964).

Fishes caught in the northeastern Chukchi and Beaufort seas were generally smaller than those caught in the northern Bering Sea (Figure 2). In the former area mean fork length was 8.8 cm (range 4.6–18.4) while in the latter area mean length was 14.7 cm (range 7.2–22.2). This difference is attributable to several factors. First, the fishes caught in the Bering Sea were generally older than those from the more northern area. In the northeastern Chukchi and Beaufort seas 1-yr-old Arctic Cod made up 81% of the catch, but in the Bering Sea they comprised only 27% of the catch. Arctic Cod older than 4 yr were caught only in the Bering Sea. Second, as indicated in Figure 2, Arctic Cod less than 4 yr old were longer at a given age in the Bering Sea than in the Chukchi and Beaufort seas. This difference was largest for 1-yr-old fishes and was progressively less in older age-classes; 4-yr-

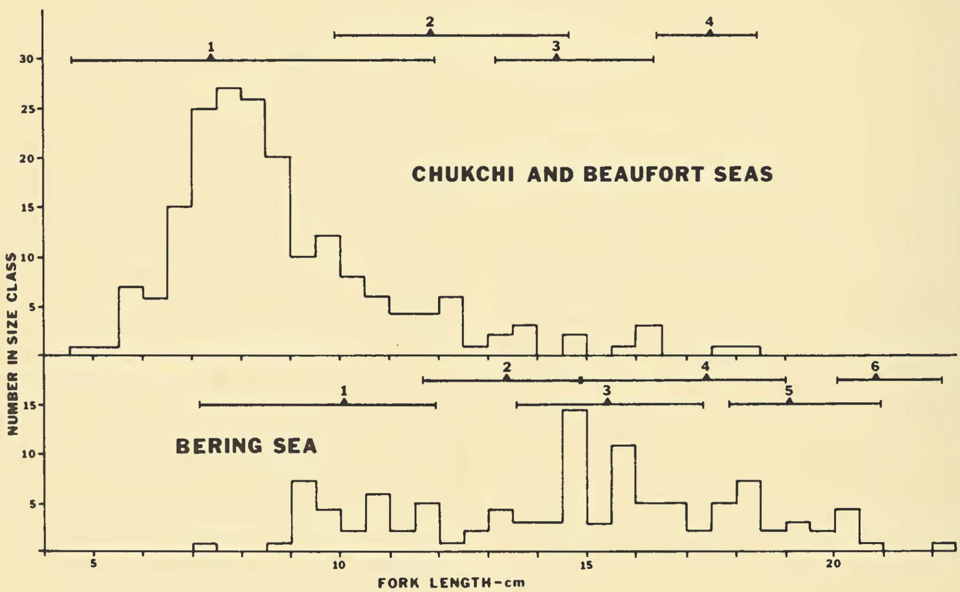

FIGURE 2. Size distribution of Arctic Cod caught in the two regions sampled. Mean (triangle) and range (horizontal bar) in size for each age-class in each region are shown above the size distributions.

old Arctic Cod were of similar length in both areas. Third, in the northeastern Chukchi and Beaufort seas small fishes (<10.5 cm) were proportionately more abundant in waters 100 m or less deep (Table 2). The size distribution of Arctic Cod from that area (Figure 2) is therefore influenced by the depth distribution of tows. Twenty-four of 33 tows were made in water 100 m or less in depth. Tows in northern Bering Sea spanned a much smaller depth range (29–80 m) and no relationship between fish size and water depth was evident.

Growth rates of Arctic Cod appear to be quite variable, especially during the first 2 yr of life (Figure 3). The transition from larvae to juvenile is reported to occur in August at a length of 3–5 cm (Rass 1968). Should we assume a mean length at transition of 4.0 cm, Arctic Cod we examined from northern Bering Sea had grown 6.1 cm in 10 mo while those from the Chukchi and Beaufort seas grew only 3.4 cm in 12 mo. First-year growth rates reported for Arctic Cod in the Barents Sea (Hognestad 1968; Gjosaeter 1973) fall between those values. Our data for the Bering Sea and that reported by Gjosaeter for the Barents Sea show the expected sequential decrease in annual length increment with age. However, in the Chukchi and Beaufort seas and in the samples from the Barents Sea examined by Hognestad, growth in length was greater in the second year of life than during the first. Hognestad found differences in postlarval growth during the first summer of life both between areas in the same year and between years at the same area. Interestingly, he found the greatest annual growth increment in the second year of life even when data for 10 sampling years was combined (Figure 3). This strongly suggests that greatest growth in length during the 2nd year of life may be common or characteristic in Arctic Cod. Reported sizes attained at the end of the 1st year of adult life vary considerably: Bering Sea, 10.1 cm; Chukchi and Beaufort seas, 7.1 cm; Barents Sea, 9.3 cm (Hognestad 1968; Gjosaeter 1973). In our samples, 4-yr-old Arctic Cod were of similar mean sizes in the Bering (17.4 cm) and the Chukchi and Beaufort seas (17.5 cm), but were smaller than that reported from the Barents Sea ($\bar{x}$ = 19.8 cm (Hognestad 1968) and 19.1 cm (Gjosaeter 1973)). Moskalenko (1964) reviewed Soviet data on growth of Arctic Cod in the Kara, Laptev, and Barents seas. He suggested two forms of Arctic Cod: a slow-growing form from coastal regions of the Kara and Laptev seas, and a fast-growing form from the Barents and Kara seas, which might be more common in the open sea. Although we cannot comment on the size and morphometric differences discussed by Moskalenko, the size at age differences observed by us and others seem adequately explained by variations in growth rates

TABLE 2—Relationship between water depth and sizes of Arctic Cod caught in the northeastern Chukchi and Beaufort Seas

Depth range (m)	Fork length Mean (range)	% in length class <10.5 cm	10.5–14.0 cm	>14.0 cm
40–100	8.2 (4.6–15.9)	89.0	10.3	0.7
101–400	10.7 (6.8–18.4)	59.6	25.5	14.9

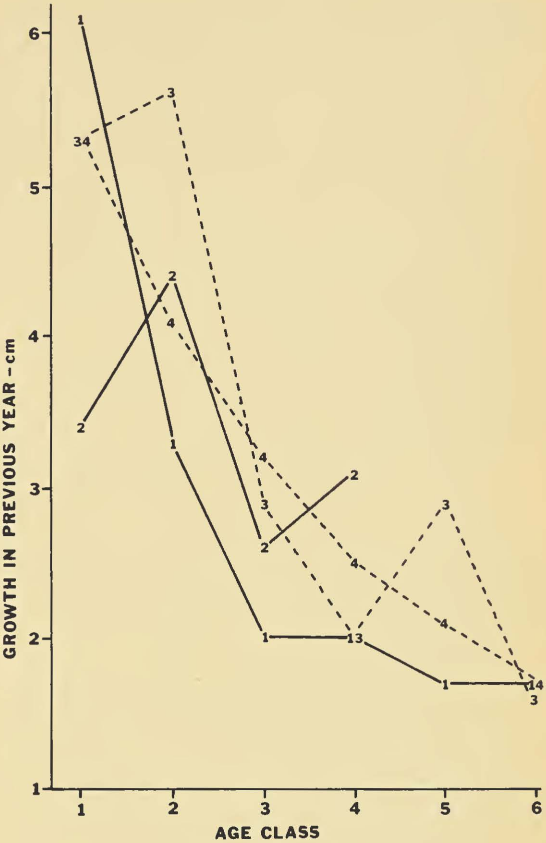

FIGURE 3. Annual growth increments reported for Arctic Cod in this study (solid lines) and other studies (broked lines).

1. Northern Bering Sea, May–June 1978.
2. Northeastern Chukchi and Beaufort seas, August–September 1977.
3. Barents Sea, August–September 1956–1966 (Hognestad 1968).
4. Barents Sea, July–September 1970–1972 (Gjosaeter 1973).

TABLE 3—Food items in stomachs of Arctic Cod collected in the northern Bering Sea, May–June 1978 and northeastern Chukchi and Beaufort seas, August–September 1977

	Northern Bering Sea, n = 73					Northeastern Chukchi and Beaufort seas, n = 157				
	Rank in stomach				Frequency of occurrence (%)	Rank in stomach				Frequency of occurrence (%)
Prey item	1	2	3	4		1	2	3	4	
Gammarid amphipod	38	11	1	—	68.4	47	40	10	—	61.8
Copepod	—	—	—	—	—	86	22	2	—	70.1
Shrimp	17	3	—	—	27.4	1	2	—	—	1.9
Hyperiid amphipod	7	—	1	—	10.9	2	7	4	3	10.2
Mysid	6	5	2	1	19.2	4	9	1	—	8.9
Euphausiid	—	—	—	—	—	2	2	1	—	3.2
Chaetognath	—	—	—	—	—	4	3	—	—	4.5
Larval capelin	4	—	—	—	5.5	—	—	—	—	—
Polychaete worm	—	2	—	—	2.7	—	—	—	—	—
Cumacean	1	—	—	—	1.4	—	—	—	—	—
Medusae	—	—	—	—	—	1	—	—	—	0.6

induced by annual variations in food availability (primary production), without invoking discrete forms in a species with a circumpolar distribution (Ponomarenko 1968).

We examined stomachs of 288 Arctic Cod. Recognizable food remains were found in 73 of 101 stomachs from the northern Bering Sea and 157 of 187 stomachs from the northeastern Chukchi and Beaufort seas (Table 3). Major prey in the northern Bering Sea, gammarid amphipods (mostly *Ampelisca macrocephala*), shrimps (mostly *Eualus fabricii* and *E. gaimardii*), and mysids (*Neomysis rayii*), were primarily benthic forms. Prey found in stomachs collected in the northeastern Chukchi and Beaufort seas indicate feeding primarily on pelagic/planktonic organisms; copepods (mostly *Calanus hyperboreus*, *C. glacialis*, *Euchaeta glacialis*, and few *Metridia longa* and *C. cristatus*) and *Apherusa glacialis*, a pelagic gammarid amphipod (Barnard 1959), were by far the predominant prey. The species of mysid eaten in this area were *Pseudoma truncata* and *Mysis litoralis* in contrast to *Neomysis rayii* in northern Bering Sea. The widely distributed hyperiid amphipod *Parathemisto libellula* was quite commonly eaten in both areas.

We examined size-related differences in foods of Arctic Cod (Table 4). In both areas, hyperiid amphipods were more commonly eaten by larger fishes, and chaetognaths were found only in smaller fishes. Overall, a greater size-related difference in foods was seen in the northern Bering Sea where the primary prey of larger cod, gammarid amphipods, and shrimps were much less commonly eaten by smaller fishes.

Similar results have been reported in other studies of foods of Arctic Cod. In the eastern Canadian Arctic, Bohn and McElroy (1976) reported copepods as the main food with pelagic amphipods and other crustaceans eaten in much smaller quantities. They found that copepods were more important in the diet of small fishes while large cod ate more shrimp. Hognestad (1968) reported that copepods were the major food of Arctic Cod collected in the eastern Barents Sea in September. Euphausiids, hyperiid amphipods, mysids, fish and shrimp eggs, phytoplankton, and small fishes have all been reported as foods of Arctic Cod in the Kara Sea (Klumov 1937; Moskalenko 1964). Similar foods have been reported from other portions of the Siberian Arctic (Moskalenko 1964).

TABLE 4—Size-related differences in foods of Arctic Cod collected in the northern Bering and the northeastern Chukchi and Beaufort seas. Only prey that occurred in more than two stomachs are included

	Frequency of occurrence (%)			
	Northern Bering Sea		Northeastern Chukchi and Beaufort seas	
Prey item	<12.0 cm	≥12.0 cm	≤10.0 cm	>10.0 cm
Gammarid amphipod	15.4	82.9	57.8	70.8
Copepod	—	—	74.2	62.5
Shrimp	15.4	46.3	2.3	4.2
Hyperiid amphipod	—	19.5	7.0	20.8
Mysid	38.5	39.0	7.0	12.5
Euphausiid	—	—	1.6	4.2
Chaetognath	30.8	—	3.9	—
Larval capelin	7.7	7.3	—	—

Our results and data available in the literature indicate considerable variability in a number of the biological characteristics of Arctic Cod. Their abundance and food habits vary both geographically and seasonally. Growth rates vary by area and by year. Abundance, feeding, and growth rates are undoubtedly interrelated in such a way that Arctic Cod optimally utilize available resources each year. Such adaptability is essential in a system with great annular fluctuations in physical (ice cover) and biological (primary productivity) characteristics and probably explains the overwhelming success of the species in Arctic waters. More data are needed before a rigorous examination of functional aspects of Arctic Cod productivity will be possible. Further studies of the biology of Arctic Cod are urgently needed to consider the ecological importance of Arctic Cod both as a potential competitor with species such as Ringed Seals (*Phoca hispida*) and Bowhead Whales (*Balaena mysticetus*) (Lowry and Burns 1980) and as a food source for many arctic marine mammals, birds, and fishes (Klumov 1937).

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