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Arctic cod in the Russian arctic: new data, with notes on intraspecific forms

Abstract

The Polar cod *Boreogadus saida*, from Siberian shelf is largely unstudied. Comparative results are presented for the Barents, Pechora, Kara, Laptev and East-Siberian seas. Surveys included 325 bottom catches, 234 pelagic and 72 Sigs by trawls at 385 stations. It is quantitatively confirmed that *B.saida* dominates in arctic areas. The maximum length is 29.0cm and age 7+ (Laptev Sea). It prefers temperatures in the range -1.8 to +2.3°C. Polar cod is represented by several intraspecific forms differing in proportions of body, size and position of fins and in coloration. It remains a mystery in what places the spawning of this fish occurs in the Arctic. A hypothesis is proposed that *B.saida* spawns in a system of winter quasi stationary polynya which may extend from the White Sea to the Chukchi Sea along the edge of fast ice. The local regimes of their functioning create the preconditions for existing of a number of stocks or populations within circumpolar range.

Keywords: polar cod: *Boreogadussaida*, dominant species, arctic, barents sea, kara sea, laptev sea, east-siberian sea, intraspecific forms, polynyas, spawning

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Introduction

Polar cod has long been recognized as a key species of Arctic ecosystems.[1] Most of the information on its biology was obtained for the Barents and Chukchi seas[2–4] but for the other arctic Eurasian regions it is fragmentary, although numerous.[5–20] The quantitative data, letting to objectively assess the role of the Polar cod in the ecosystems of this vast region, is insufficient. This study attempts to fill this gap.

Areas of work

In 2012-2014 the author took part in large-scale trawl surveys in the Barents, Pechora, Kara, Laptev and East-Siberian seas (Figure 1). In zoogeographical terms, the sampling covered mainly the areas of distribution of the Arctic fish fauna, namely the Kara Sea (areas EN1, EN2, EN3 below), the Laptev Sea (areas O, L, AN) and the East-Siberian Sea (part of the AN area). The exception was the Barents Sea (CB area), where the research captured the zone of the Polar front separating the subarctic (F) and the Arctic (P) faunas. The Pechora Sea (areas MV and SR), situated on the southeast of the Barents Sea, also belongs to subarctic regions. Studies cover depths from 2 m to 414m.

Volume of work

Trawl surveys were conducted at 385 stations and included 325 bottom catches, 234 pelagic catches and 72 works by Sigsbytrawl (Table 1). The stations were located in the Barents Sea (95 in number), in the Pechora Sea (41), in the western Kara Sea (120) and in the Laptev and East-Siberian seas (129).

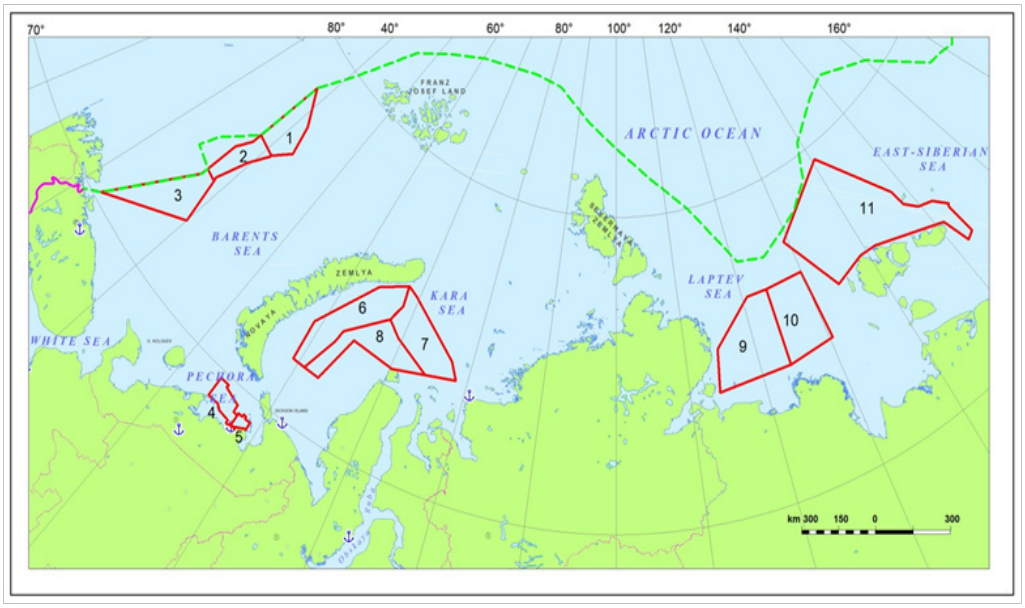

Figure 1 Areas studied. Work sites: 1 - P, 2 - CB, 3 - F, 4 - SR, 5 – MV, 6 - EN1, 7 - EN2, 8 - EN3, 9 - O, 10 - L, 11 – AN. The green line indicates the sea waters of the Russian Federation.

Table 1 Characteristics of studied areas and number of samples.

Seas and areas[1]	Coordinates of the utmost points of the areas		Dates of sampling	Depth, m	Number			
	n	e			Stations	Bottom	Pelagic	Sigsby
Barents sea								
P	76 03–78 37	38 00–43 00	04.06-23.06.2013	137-301	30	30	30	-
CB	73 54–76 10	37 00–41 06	29.05-14.06 2013	136-301	25	25	25	-
F	70 19–73 58	32 10–40 00	31.05-14.07 2013	170-355	40	40	40	-
Subtotal					**95**	**95**	**95**	-
Pechora Sea								
MV	68 45–69 20	57 30–59 00	18-24.07 2013	2-18	15	7	-	19
SR	69 00–69 46	53 57.7–57 36.8	28.07-08.10 2012	11-77	26	14	12	13
Subtotal					**41**	**21**	**22**	**32**
Kara Sea								
EN1	71 52–76 43	59 03–68 21	28.09-06.10 2012	76-414	40	40	40	-
EN2	73 45–76 03	67 28–78 29	13-24.09 2012	15-300	40	37	19	3
EN3	71 51–74 50	60 59–76 26	11.09-01.10 2012	15-215	40	31	26	9
Subtotal					**120**	**108**	**85**	**12**
Laptev Sea and east-Siberian sea								
O	74 19–76 48	114 08–124 06	12.09-09.10.2014	10-94	34	19	11	15
L	74 29–76 48	123 56–130 21	8-30.09.2014	15-94	25	24	12	1
AN	74 05–79 34	129 13–153 09	19.08.14-08.09.14	9-353	70	58	19	12
Subtotal					**129**	**101**	**42**	**28**
Total	68 45 – 79 34	**32 10 –153 09**	**2012 – 2014**	**2-414**	**385**	**325**	**234**	**72**

Bottom –bottom trawls, Pelagic – pelagic trawls, Sigsby – works by Sigsby trawl.

Methods

Work was carried out on board of the RV "Dalnie Zelentsy" (Murmansk Marine Biological Institute of the Kola Scientific Center). The instructions of the Polar Institute of Fisheries and Oceanography (PINRO) for fishery research [21] were used for fish studies. Trawl surveys were accompanied by a complex of hydrological work. The salinity and temperature of water were measured by device SBE 19plus V2.

The works in the Barents Sea were carried out using the trawl (No. 2837-00-000, Sevrybproyekt), horizontal and vertical opening of 22 and 10m respectively. In the other seas, the survey was performed by a trawl (No. 2387.02.155) with a horizontal and vertical opening of 17 and 3-5m. The bag and wings of trawls had a mesh of 135mm, the mesh of insertion was 12 mm. Bottom trawling was carried out at a speed of 2.4-2.6 knots, pelagic ones were done at a speed of 3.5-4.0knots; the duration of trawling was 30minutes. A Sigs by trawl was used for work in shallow waters at depths of 10-20 m (frame 100x30cm). All catches were recalculated per unit of effort (individuals or kg per hour of trawling). Coefficient of catch ability was assumed to be equal to unity. All photos are original and have been produced on board. Some of them were obtained during the Russian-American expedition in the Chukchi Sea in 2009 (August, 23 -September,30), RUSALCA program.

Results

Barents Sea

In this extended area of research, stretched from the south to the north (areas F, CB, P), the Polar cod was encountered almost

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exclusively to the north of the Polar front. The frequency of occurrence in the north (area P) reached 77% (Table 2), and the share in the catches by abundance was 77.5% (Table 3). Contrarily, it was caught only sporadically in the remaining two areas (CB and F). North of the Polar Front, the Polar cod dominates the fish complex in abundance and occupies the second place by biomass (after the long-rough dab *Hippoglossoidesplatessoideslimandoides*). It was caught mainly at the bottom: 99.7% of its numbers was accounted for by bottom trawling (and only 0.3% by pelagic trawling). In this area the Polar cod is common part of the ration of the long-rough dab; in a half of the stations where this dab was caught, *B. saida* is found in 20 - 100% of its stomachs. This fact confirms the habitation of the Polar cod in the bottom waters. The temperature of the water where the Polar cod was caught varied from -1.6 to +1.3C (Table 4); and most of the occurrences occur in waters with negative temperatures. At a few stations where the Polar cod was caught in the pelagic (7%), the surface water temperature was about 0°C.

Table 2 The frequency of occurrence of the polar cod at the bottom and in the pelagic in the investigated seas and its maximum length

Areas	Biog	OC, %			Prop, %		TL, Cm
		Bottom	Pelagic	Average	Bottom	Pelagic	Average
Barents Sea							
P	a	77,0	7,0	77,0	99,7	0,3	20,5
CB	tr	16,0	0	16,0	100	0	17,0
F	sub	2,5	0	2,5	100	0	15,5
Pechora Sea							
MV	sub	14,0	-	14,0	100	-	9,7
SR	sub	7,1	0	3,8	100	0	10,0
Kara Sea							
EN1	a	97,5	32,5	97,5	86,7	13,3	23,2
EN2	a	67,5	42,1	75,0	78,0	22,0	20,5
EN3	a	64,5	15,6	60,0	96,7	3,3	17,6
Laptev Sea and East-Siberian Sea							
O	a	94,7	45,5	76,0	87,3	12,7	28,5
L	a	95,8	33,3	96,0	97,1	2,9	29,0
AN	a	100,0	32,0	90,0	98,9	1,1	27,0

Abbrevations: OC, frequency of occurrence; prop, proportion of the polar cod (by numbers)in catches at the bottom and pelagic; TL, total length, maximum for the area; Biog, biogeographical characteristic of fish complex, a – arctic; SUB, subarctic; Tr – transitional; bottom, in bottom trawl catches; Pelagic, in pelagic catches; Average, The average on the area; "-" - there were no samples.

Table 3 The share of the Polar cod in the total catch of fish in the studied seas, in number and biomass.

Areas	Biog	N, %			B, %		
		Bottom	Pelagic	Average	Bottom	Pelagic	Average
Barents Sea							
P	a	77,8	30	77,5	30,3	28,7	30,3
CB	tr	1,7	-	1,7	0,0	-	0,0
F	sub	0,17	-	0,17	0,0	-	0,0
Pechora Sea							
MV	sub	1,3	-	1,3	0,1	-	0,1
SR	sub	0,1	-	0,1	0,0	-	0,0
Kara Sea							
EN1	a	68,6	86,9	70,6	38,7	31,5	38,5

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Table Continued

Areas	Biog	N, %			B, %		
		Bottom	Pelagic	Average	Bottom	Pelagic	Average
EN2	a	38,1	66,1	35,7	41,9	36,3	37,8
EN3	a	52,8	44,1	44,8	21,3	2,4	17,2
Laptev Sea and East-Siberian Sea							
O	a	78,7	95,74	44,3	60,6	97,5	61,12
L	a	88,4	94,3	76,3	77,5	98,9	77,4
AN	a	74,9	100	70,4	35,2	100	35,3

Abbrevations: B, share of total catch of all fish species by biomass; N, share of total catch of fish of all species by number; biogeographical characteristic of fish complex, a – arctic; sub, subarctic; tr, transitional; Bottom, in bottom trawl catches; Pelagic – In Pelagic Catches; Average - the average on the area; "-" - there were no samples.

Table 4 Conditions for the presence of Polar cod in the investigated seas[1]

Areas	Temperature, °C		Prop, %	Salinity, ‰		Oxygencontent, %	
	A	B		A	B	A	B
Barents Sea							
P	–0,6+1,3 –1,6+1,0	–1.6+1.3	45	34,10-34,90 34,78-35,02	34,62-35,00	81,0-113,0	78,5-97,0
CB	+0,3+4,5 –1,0+0,2	–0.64 - –0.52	100	34,65-35,08 34,95-35,00	34,94-34,97	93,0-113,0	89,7-97,0
F	+3,5+10,8 –0.2+4.8	+0,45	100[2]	34,9-35,10 34,90-35,00	34,98	89,0-109,0	86,3
Pechora Sea							
MV	12.8 +18.3 –1.7 + 2.0	–0.28	100[2]	16.50 – 30.00 32.00-33.20	33,03	82,0-104,0	93,6
SR	+8,8+10,9 +0.89+10.57	+2,07	0[2]	28,52-33,79 29,93-34,28	33,2	86,5-114,3	93,76
Kara Sea							
EN1	+4,63+9,09 –0,33+0,93	–1.0- –0.01	100	32,53-33,44 34,03-34,49	33,92-34,47	81,3-105,1	80,6-105,1
EN2	+3,93+6,74 –1,61+5,19	–1.06+6.4	75	13,32-32,76 29,74-34,40	29,74-34,4	81,3-108,3	88,0-98,0
EN3	+5,1+8,8 –1,04+6,41	–0.98+5.19	80	18,40-33,60 24,40-29,70	29,74-34,5	80,2-106,7	86,0-101,0
Laptev Sea and East-Siberian Sea							
O	1,97+4,24 –1,77+3,15	–1,77+2,3	87	27,59-32,69 29,02-34,77	30,05-34,7	84,9-99,3	85,0-97,1
L	+1,46+6,16 –1,8+2,76	–1,74 - –1,16	100	19,43-33,68 19,27-34,84	33,60-34,76	73,0-99,3	68,46-91,63
AN	+1,23+5,73 –1,72+1,54	–1.70 +3.74	70,8	19,43-33,68 19,27-34,98	(19,96; 22,69) usually 27,39-34,98	58,8-103,3	(59,7; 63,56) usually78-95%

Abbrevations: A, throughout the area; B, in places of Polar cod presence; Prop, The share of cod occurrences at negative temperatures;

1, The numerator contains data for the surface layer, in the denominator for the bottom layer of water. 2, one measurement.

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In the zone of the Polar front (area CB), where the environmental conditions are highly variable, the Polar cod was caught only at the northernmost stations, exclusively at the bottom (at depths of 230-290m) and at negative temperatures.

To the south of the Polar front (area F), in warm waters (with temperatures from -0.2 to +10.8C), the Polar cod is found only on the northernmost and deepest (325m) station, at a low positive temperature (0.45°C). The absence of *B. saida* south of the Polar front is confirmed by the fact that it was not found in the stomachs of predatory fish of this area, namely in cod *Gadusmorhua* (462 specimens), haddock *Melanogrammusaeglefinus* (241), three species of wolffishes (36) and long-rough dab(297).

North of the Polar front (area P), the abundance of *B. saida* averaged 75.6ind/effort (with the highest catch of 548 ind/effort), or 1505 ind/km^2 (Table 5). They were mostly young specimens (TL 12-15cm, 75% of the catch), which explains the low absolute values of the biomass, which averaged 1.2 kg/effort, or 23.7kg/km^2 (with the highest value of 168 kg/km^2).

Pechora Sea

In bottom catches, the Polar cod was only met at one, the most northerly and deep station in this area (21.5m). For a wide variability of environmental conditions (temperature from -1.7°C at the bottom to 18.3°C at the surface, salinity from 16.50 to 33.20‰), the Polar cod was caught in waters of negative temperature (-0.28°C) and a relatively high salinity (33.03 ‰).At lesser depths, close to coast of Varandey, the Polar cod was not caught by any gears. The fish complex was dominated by Nawaga *Eleginusnawaga*, and the share of *B.saida* was only 1.3% in abundance and 0.1% in biomass. Only juveniles, TL 9.3-9.7cm long, were exclusively caught. At the exit from the Pechora Bay (area SR), the Polar cod was practically absent.

Thus, in the Barents Sea, the Polar cod is one of the key species in ecosystem northward of the Polar front: it dominates in abundance, and biomass ranks second after the long-rough dab. To the south of Polar front and in the coastal areas of the Pechora Sea, *B. saida* presence is vanishingly small.

Kara Sea

The cold waters of the open sea being inhabited by the Arctic fish fauna, are not productive; the total fish biomass is low (on average 0.3-1.7kg/effort).In the area of Novaya Zemlya trough (EN1), maximum abundance and biomass of the Polar cod did not exceed 284ind/effort and 4.62kg/effort, with the averages 47.4ind/ and 0.63 kg / effort. Despite the low absolute catch in the west of the Kara Sea, the Polar cod dominated by abundance (70.6%) and biomass (38.5%). As in the Barents Sea, the Polar cod was found mainly at the bottom, being caught by majority of bottom trawls (97.5%) but in part of pelagic (32.5%). The distribution of *B. saida* over the area was uneven, with the highest concentrations observed at depths of more than 100m.

Table 5 Quantitative data of Polar cod catches in the studied seas

Areas	Abundance, ind / Effort		Density, ind/ km^2		Biomass, kg / Effort		Density, kg/km^2	
	Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum
Barents Sea								
P	75,6	548	1505	11297	1,2	8,14	23,7	168
CB	1,6	20	25,7	322	0,02	0,3	0,4	4,92
F	0,2	8	3,9	155	0,0	0,13	0,06	2,6
Pechora Sea								
MV	0,6	4	3,7	56	0,0	0,02	0,06	0,852
SR	0,1	2	0,7	-	0,0	0,02	0,01	0,1
Kara Sea								
EN1	47,4	284	516,1	3096	0,63	4,62	6,91	50,3
EN2	19,0	154	207,1	1679	0,13	2,2	1,44	23,9
EN3	22,5	426	244,7	4709	0,15	2,14	1,66	23,4
Laptev Sea and East-Siberian Sea								
O	124,7	576	65,8	453	1,28	3,34	12,79	33,4
L	141,6	1264	1420,2	12780	2,69	36,1	26,95	361,9
AN	93,6	1080	1107,2	9013	1,0	11,4	10,02	12,6

In the shallow Kara Sea northward of the islands Beliy and Wilkitsky (area VP-2), fish catches were absent (at 18% of the stations) or insignificant (up to 2.8kg/effort). However, the most common species was the Polar cod. In general, it dominated in fish community in abundance (35.7% of total catch) and biomass (37.8%). The exception was a few shallow coastal stations (15-20m), sampled by the Sigs by trawl, where the Arctic staghorn sculp in *Gymnocanthustricuspis* (92.6%) was number one in biomass, while the share of *B. saida* did not exceed 4.1%. It should be noted indeed, that the Polar cod was represented there mainly by young (5.5-7.0cm in length), but its abundance (635.6ind/ km^2) was significantly higher here than in the rest of the water area (207 ind/km^2). These shallow coastal waters with summer warming represent a growing-up place for many fish species, including the Polar cod.

A lot of one-of-the year juveniles of 5.2 to 7.0cm in length, were also caught in the pelagic layer, still not settled to the bottom. It may indicate that *B. saida* has spawning grounds in surroundings.

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A similar picture was observed in the shallow water north-west of the Yamal Peninsula (EN3). In abundance, the Polar cod was dominant among other species (accounting for 52.8% of bottom catches). Up to 80% of its samples occurred in waters with negative temperatures. According to biomass, it was approximately equal to the share (17.2%) with two other common fishes, *Eleginusnawaga* and Capelin *Mallotusvillosus* (18.7% and 18.5%). In shallow water (10-20m), where the Arctic staghorn sculpin *G. tricuspis* dominated, her share in the catches was insignificant (1.4% in biomass, 3.21% in abundance). *B. saida* formed the largest concentrations (180-426 ind/effort) in deeper localities (150-186m).

The Laptev Sea and East-Siberian Sea

In the vast cold area of the investigated shelf, the biomass of fish of all species was insignificant, amounting to 1.5-3.3kg/effort, or 21.1-34.8kg/km^2. The fish abundance (1606.5-1477.8 ind/km^2), in contrast, was comparable to the Barents Sea quantity. This phenomenon is due to the small size of the fish species inhabiting the Arctic areas (families Cottidae, Liparidae, Zoarcidae, Lumpenidae).[22] Fish were concentrated mainly at the bottom. Significant accumulations of juveniles of Arctic fishes were observed in the warmed shallow water (9-20 m); according to the Sigs by catches, their density averaged 1449-1836 ind/km^2 and 10.6 -11.6 kg/km^2 there.

In the areas to the north of Olenek delta, Lena delta and northward of the Kotelniy Island (O, L, AN) *B. saida* was the most common and abundant fish in the bottom habitat. It dominated also in biomass. Almost half of the pelagic trawls (45.5%) contained a significant number of one-of-the-year juveniles (4.0-6.0cm in length).These planktonic fry still did not shift down to the bottom. The amount of such young at sea, obviously, was significant. A lot of juveniles were also noted in shallow waters (10-15m).

In absolute terms, the biomass of the Polar cod was insignificant: on average, 2.7kg/effort and 26.95kg/km^2. At the same time, its abundance was quite high: 141.6 ind/effort and 1420.2 ind/km^2, which is comparable to the data for the Barents Sea northward of the Polar front (area P). The maximum catch of *B. saida* (11-36kg and 1.1-1.3 thousand specimens per hour of trawling) was obtained in the north of the area, at a depth 124-455m. The abundance also increased in the direction to waters around islands (up to 7,4 kg/effort). However, in shallow (13-18m), warm and markedly freshened waters (temperature 0.37-4°C, salinity 19.27-25.25‰), the Polar cod was absent.

In general, in all Arctic areas studied, the temperature range was registered from -0.6 to +9.1°C in surface layer, and from -1.8 to +6.4°C in bottom layer (being the highest in shallow localities). However, the Polar cod was caught in the limited range from -1.8 to +2.3°C in the overwhelming majority of cases; with 70-100% of sampling at negative temperatures. It is justified to consider these meanings as thermo preference of the Polar cod.

In all studied Arctic areas, the salinity range was registered from 13.32 to 34.90‰ in surface layer and from 19.27 to 35.08‰ in bottom layer. However, the Polar cod was caught in the limited range of rather high salinity, 27.39-35.00‰, in the majority of cases. Oxygen content was 68.5-105.1 %.

The largest length of the Polar cod was observed in the Laptev Sea, TL 29.0cm. The specimen was a female at the age of 7+. Males were smaller than females, and the largest reached a length of 27.0cm at the age of 5+. The Polar cod in the Kara and Laptev seas is somewhat larger than in the Barents Sea, which probably can be explained by the absence of its fishery in former regions.

The Polar cod had an age from 1+ to 4+ years in the Barents Sea, to 6+ years in the Kara Sea and to 7+ years in the Laptev and East-Siberian seas. The main part of the total catch (70-80%) was formed by fishes aged accordingly as 2+, 2+3+ and 1+4+. The number of males was slightly higher than the number of females in the majority of samples, in proportion 1.0 to 0.6-0.9. Most of the catches in all areas were immature fish that had gonads in the stage of maturity II. In the Barets Sea (area P) a part of individuals - 17.7% of females (TL 11.8-20.5cm), and 29.6% of males (TL 12.5-19.5cm), were in a state after spawning (stage of gonad maturity VI-II). Some amount of post-spawning specimens was observed also in the Laptev Sea.

The polar cod was actively feeding in all areas (259-698 specimens were examined at each). Food mainly consisted of euphausiids and *Calanus*, as well as hyperiids (*Temsto*), mysids, amphipods, Cumacea, polychaetes, ctenophores, bivalves, sagitta and small fish (Capelin, *Boreogadus, Lumpenus,* cottids). The stomachs of juveniles 4,0-7,0cm (age 1+) were filled mainly with copepods (*Calanus*). The most variable food (16 items) was found in the Laptev Sea. It contained mainly crustaceans and fish, in a small number there are also polychaetes, ctenophores and jellyfish. Hyperiids, amphipods and *Calanus* are present in the diet of the Polar cod at 66-78% of the stations, with the occurrence of 80-100% in stomachs. Fish-items were registered in 2-34% of Polar cod samples; with 4 to 50% of their frequency in the stomachs.

The Polar cod itself was the main food of the Greenland halibut *Reinhardtiushippoglossoides* at the edge of shelf in the Laptev and East-Siberian seas (91% of occurrence).[23]

Forms of the Polar cod

Circumpolar range of *B. saida* is huge[24] Regional differences in habitat are determined not only by the orography of basins, but also by the presence of different types of water masses in the region (Figure 2).[25] The diversity of local conditions suggests that the Polar cod can be heterogeneous throughout its range. Indeed, in the Barents and Chukchi seas, in the waters of Greenland, few local stocks are distinguished, with their inherent migrations throughout the life cycle. However, at the rest of the Arctic shelf, from the Kara Sea to the East Siberian, the stocks or populations of the Polar cod are not distinguished. Our materials have shown that the Polar cod is represented by several forms in these waters. Preliminary, one can state that these forms differ in proportions of body, in size and position of fins and in coloration (Figures 2-5). The differences have yet to be clarified.

The Polar cod was described as *Gadussaida* by I.I. Lepekhin[26] (1774: 512, Pl. 5) figure 1) on individuals from the White Sea, which are belonging to the East-Barents-Sea population (=typical form).This form is characterized by a back with a hump behind the high occi put, and an elongated caudal part (Figure 2A). In the Kara Sea, one can distinguish three forms. One of them has a uniformly high massive body, a relatively short tail and a characteristic pink tint of color (Figure 2B). Polar cod of the second form is low and elongated, with symmetrically elliptic contours of body, and dark gray color (Figure 2C). The Polar cod of the third form has a sharpened conical snout, a disproportionately massive trunk and weak caudal part of body, small unpaired fins, and unusually gentle consistency of skin and muscles; the skin is bright black dotted (Figure 2D). In the Laptev and East-Siberian seas, one can distinguish a form with a strong and elongated caudal part, high unpaired fins, a blackish back and a bright, silvery white lower surface of body, strong pectoral fins (Figure 3A). The second form has a straightened upper contour of body and a close

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to superior mouth; by the pinkish color it is similar to the pink form from the Kara Sea (Figure 3B). The third form differs from all others by a very low body, almost cylindrical in cross-section, and a strong caudal fin (Figure 3C). In the Long Strait, there is a light humpbacked form with a high-set pectoral fin, with a white belly and pink stripe above the mid- line of the body (Figure 3 D). Several forms of *B. saida* are also distinguishable in the Chukchi Sea. At a depths of the north-eastern part they are: a dark form, similar or identical to that one of the Kara Sea (Figure 2C); and also a form with a strong caudal part (Figure 4A), similar to that one from the Laptev Sea (Fig. 2A).At shallow depths, a form occurs which is similar in body shape (Figure 4B) to that one from the Long Strait (Figure 2D). Polar cod from the southern Chukchi Sea (migrating from the Bering Sea?) has a low-curved upper contour of the body, deeper curved lower contour and a high at the beginning caudal part of body (Figure 4C). Apparently, the morphological features of all these forms of *B. saida* can be explained by some differences in nature of habitats and modes of lifestyle. Probably, such diversity indicates the existence of a few stocks and / or its ecological forms of the Polar cod. Special research is needed on the population structure of the species, including studies of the local characteristics of the life style within enormous circumpolar range.

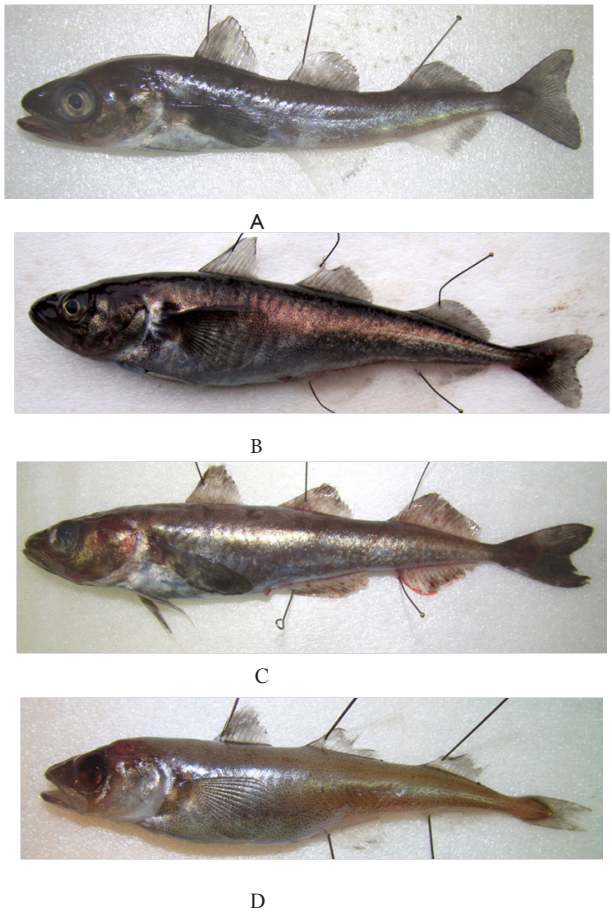

Figure 2 Polar cod *B. saida*. Barents Sea: A–TL 15cm, 77°13'8N, 39°15'3E, depth 208m. Kara Sea: B-TL 18,5cm, 75°55,3N, 68°02,1 E, depth 300m; C - TL 18,9cm, 74 45,8 N, 70 32,2E, depth 29m; D - TL 12,4 cm, 71 54,9N, 62 52,9E, pelagic trawl above the depth 120m.

Spawning grounds in the Arctic seas

Over the vast range of the Polar cod, two regions of mass and annual spawning are well documented, west of Spitsbergen and in the Pechora Sea. In cold decades, when the Polar cod has a high stock abundance, part of the Pechora population comes to spawn into the White Sea. *B. saida* reproduction in the White Sea is described in details.[27–29] For all other localities it remains a mystery where the breeding occurs. The spawning areas are unknown, probably because the polar cod reproduced in winter and outside of coastal zone.

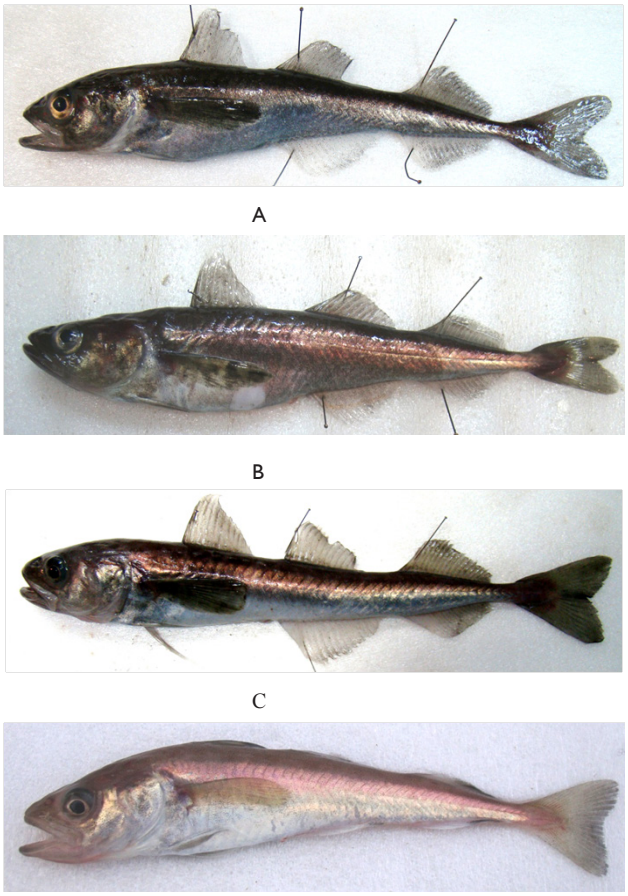

Figure 3 Polar cod *B. saida*. Laptev Sea: A - TL 23,3cm; Olenek-River area, 76 04 21N, 123 58 59E, 53m; B - TL 227mm, 78 21 51N, 136 13 26E, 195m; C - TL 29,0cm; Olenek-River area, 76 03 N, 124 01 E, depth 53,5m. Long Strait: D - TL 16,8cm, 70 20.50N, 181 39.50E, 49m.

In our study a lot of pelagic juveniles of *B. saida* (Figure 4D) were caught in surface waters, from the Kara to the East-Siberian seas. A large proportion of juveniles in catches allow to conclude that there are local spawning grounds in these regions. The following hypothesis is proposed. It is known, that in winter the coastal fast ice zone on the Arctic shelf has a width of several tens of meters to hundreds of kilometers (Figure 3)[25]. In the space between the edge of fast ice and continuous fields of perennial pack ice of the Central Arctic, a system of quasistationary polynyas is formed in winter, which is a zone of open water and young ice, unstable and mobile. These are zones of high biodiversity, of great importance for the functioning of Arctic ecosystems. The net of polynyas is vast and extends more of less continuously from the Mezen Bay of the White Sea (Gukov, 1999, (Figure 1)[30] and from the western Yamal peninsula in the Kara Sea to the Vrangel Island in the Chukchi Sea (Figure 3).[25] The polynyas can be an ideal place for spawning of the Polar cod along the entire Arctic coast because of: the formation time (winter period), the presence of

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an extended ice edge, temperature conditions (close to 0°C, preferable for spawning).The spring development of phytoplankton and zooplankton in polynyas provides favorable feeding conditions for the larvae of *B. saida*. The large extention of polynyas and the differences of the local regimes of their functioning create the preconditions for the formation of a number of local populations of Polar cod within its extensive range.

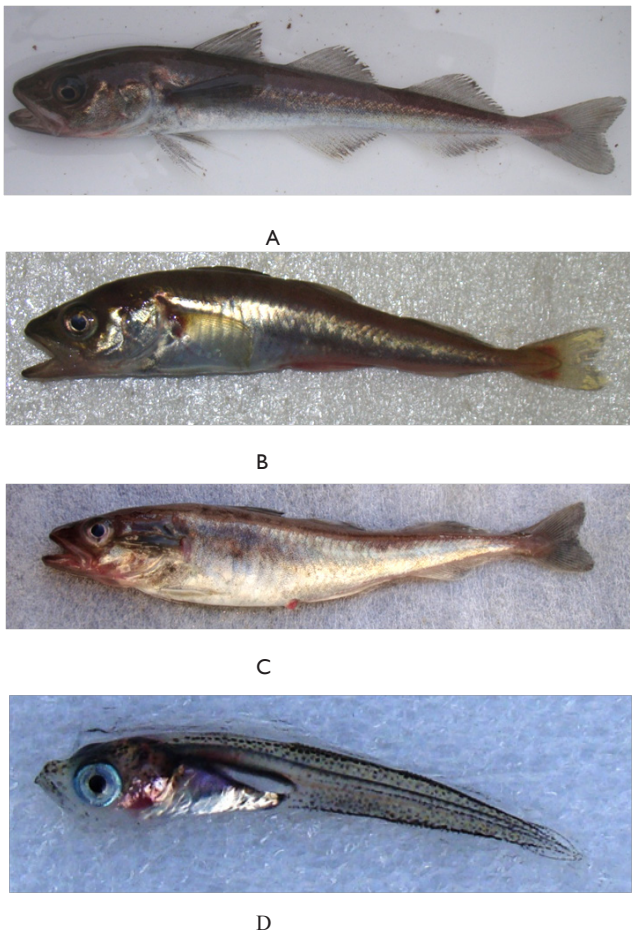

Figure 4 Polar cod *B. saida*. Chukchi Sea, north-eastern part: A – TL 16cm, 74 29.04N, 165 58.022E, 365-370 m; B–TL 123mm, 69 41.93N, 174 38.53 E, depth 50m. Southern part:C - TL 18,2cm, NE of Serdtze Kamen', 67 26.8N, 169 33.18E, depth 51m. D – planktonic larvae, TL 27mm; Long Strait, 69 48.94N, 177 56.49 E, 44m.

Discussion and conclusion

Our quantitative data show that the Polar cod is a common and abundant fish at all studied Arctic areas in ice-free period. In the Barents Sea, it occurs north of the Polar Front, and in the seas from Kara to the East-Siberian it is present almost everywhere. The Polar cod dominates in abundance and biomass, concentrating mainly at bottom and in deeper localities (down to 412 m in our study). On the contrary, in the subarctic areas (southward of the Polar Barents front, as well in the Pechora Sea) the occurrence and abundance of *B. saida* are vanishingly insignificant.

Our results on Polar cod dominance correspond to previous data for the Kara Sea (which is better studied than other areas).[8] At the same time, in miscellaneous publications, huge shoals of Polar cod are mentioned, sporadically approaching the shores of Novaya Zemlya and the mainland coast: the Baydaratskaya and Kara Bays, Gydansky Bay, Yenisei Gulf and the Pyasina Bay. [10,20,31] During our research, such massive shoals of the Polar cod were not registered, which indicates their irregular or seasonal (pre-spawning?) occurrence.

The cold shelfs of the Kara, Laptev and East-Siberian seas, inhabited by the Arctic fish fauna, are not productive, and the total fish biomass there is scarce (on average 0.9-3.3kg/effort). By number of species the families Zoarcidae, Cottidae and Liparidae are dominated. Indeed, the Polar cod occupies a dominant position in abundance (38-88% of bottom catches) and the same or subdominant position in biomass (21-77.5%). The exception is the in shores hallow water (15-20m), where the biomass is dominated by Nawaga (*Eleginusnawaga*) or the Arctic staghorn sculpin (*Gymnocanthustricuspis*), although the Polar cod is represented there but by small juveniles (5.5-7.0cm). Thus, the Polar cod can reasonably be considered a key species of arctic ecosystems in seas from the Kara to East-Siberian. In the Laptev and East-Siberian seas, the abundance of Polar cod (up to 1107-1420.2 ind/km^2) is comparable with the data for the north of the Barents Sea (1505 ind/km^2).

According to our data, the largest size of the Polar cod (29cm) and the maximum age (7+) are recorded for the Laptev Sea. This value is close to the largest size of the Polar cod (30cm) found in the Kara Sea.[9] But for the Barents Sea the fishes of 40cm length and the age of 8+ are recorded, although usual size is 12-24cm there.[3]

In all regions, the males slightly predominate in the catches over the females. It probably can be explained by high proportion of unmature specimens in catches, as in older year groups the females predominate.[3]

Food. According to long-term data for the Barents Sea, the diet of Polar cod is diverse and includes 61 species; 10-12 items are of primary importance; and in the annual ration the first are copepods (42% by mass) and the second are fish (27%).[32] According to our data, feeding is most diverse in the Laptev Sea, where 16 components were determined in *B.saida* stomachs in field conditions. The composition of food varies with age. Juveniles up to 5.0-7.0cm feed mainly on *Calanus*. The main food of fish 10-13cm long and over was crustaceans and small fish. Large specimens are mainly fed by fish (including the young of its own species).

It is interesting to mention the feeding of the Polar cod by phytoplankton. A member of the expedition of 1934 on the icebreaker "Georgy Sedov" P.I. Usachev in the northeastern part of the Kara Sea (79°N, 80°E, 2-5.08.1934) noted feeding with diatoms in the zone of thawed water formed during the melting of ice.[5] Stomachs contained, along with zooplankton, a large amount of greenish mass consisting of *Fragillariaoceanica*, *Thalassiosira*, *Nitschiafrigida*, *Melosiraarctica*, *Chaetoceros*, which are typical representatives of the sea-ice flora. The phytoplankton is also mentioned for the feeding of the Polar cod in the Kara Bay.[9] In the course of our studies, diatoms were not detected in the stomachs of this fish.

The Polar cod itself was the main food of the Greenland halibut *Reinhardtiushippoglossoides*, abundant near the edge of the Laptev-Sea slope, in warm water masses of the Atlantic origin.[33,34] Other predators that can be fattened by the Polar cod are Greenland Shark *Somniosus microcephalus* and Polar skate *Amblyrajahyperborea*, the recent capture of which in the north of the Laptev Sea (about 240m) suggests their permanent habitat along the slope in the same warm waters mass.[34] On the other hand, large predatory fish are not recorded

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on the cold shallow shelf of seas from Kara to East-Siberian. In these areas the Polar cod, mainly juveniles, can be fed by large specimens of arctic sculpins (*G.tricuspis*, *Myoxocephalus*sp.), zoarcids (*Lycodes*), as well as by the East-Siberian cod *Arctogadusborisovi.*[34]

In studied areas, the salinity range varied from 13.32 to 35.08‰. However, the Polar cod was caught mainly in the limited range of high salinity, 27.39-35.00‰. Waters in the investigated areas were locally warmed up, but the temperature range at which the polar cod was caught varied from -1.8 to +2. °C; and 70-100% at negative values. The temperature range from -1.8 to 2.3°C can be considered as the thermo preference of the Polar cod. It is in accordance to data for the Barents Sea.[3] Under climate warming, if the temperature will exceed the upper limit of this range, the Polar cod obviously will escape from the area, and hence from the trophic networks. The consequences of water warming in seasonally ice-free areas will affect numerous consumers of Polar cod, such as carnivorous fish, marine birds and sea mammals.

Acknowledgment

None.

Conflict of Interest

None.

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