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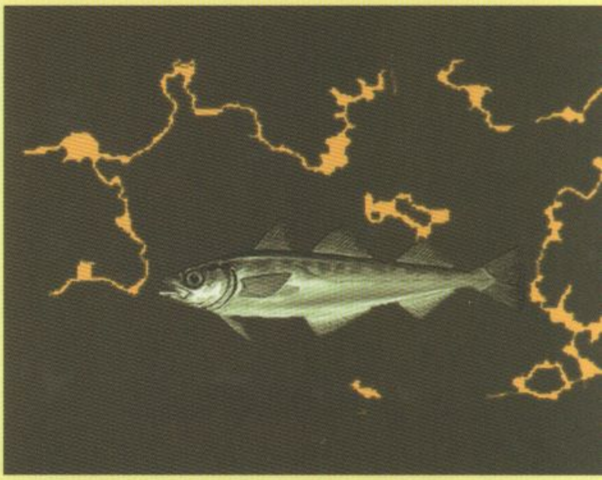
# Walley pollock *Theragra chalcogramma* from the Navarin region and adjacent waters of the Bering Sea:

## ecology, biology and stock structure



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# Walleye pollock *Theragra chalcogramma* from the Navarin region and adjacent waters of the Bering sea: ecology, biology and stock structure

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Walleye pollock Theragra chalcogramma from the Navarin region and adjacent waters of the Bering sea: ecology, biology and stock structure.— M.: VNIRO Publishing, 2007.— 180 p.

Finding out the population structure of pollock is a complex procedure because of the species' seasonal and ontogenetic migration intensity which undergoes significant interannual variations as dependent on the climate and ocean conditions, the abundance of population, and of the species in total. That is why, in order to obtain a comprehensive picture, the book reviews the results of a decade of integrated research (1996—2004) which included 26 cruises, 21 trawl surveys, 11 echointegration trawl surveys, 8 surveys of the juveniles and five ichthyoplankton surveys made in the northern, western and eastern parts of the Bering Sea where a novel approach developed by VNIRO was applied which involved serial repetition of surveys during a year. For the first time the results of such surveys made it possible to obtain information on the stock structure dynamics. The monograph reviews the organization of the Bering Sea pollock population using a virtually full set of approaches to the study of populations: genetic, ecological (biogeocenotic), morphological, biochemical, physiological, geographic, energy and ethological. The functional structure dynamics of the range between the 1970s and the present time was analyzed, as based on the own and published data.

The book is designed for experts in marine biology and ecology, fish biology, hydrobiology, oceanology, genetics, physiology, and for the staff of fishery management organizations.

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# INTRODUCTION

The Navarin-Koryak waters which make only 4.3% of the Bering Sea area provide 23.9% of the annual mean catch of pollock in the entire Bering Sea, and this share has grown up to 29.2%, since closure of the large-scale pollock fishery in the enclave in 1994. Despite a high bioproductivity of the North Bering Sea, there is no unanimous agreement on the origin of the pollock stock in these waters. Meanwhile the long-term sustainable fishing for the North Bering Sea pollock could be guaranteed only through development and implementation of a fishery management regime applicable to the elementary self-regulating unit, i.e. a stock or a population. At the turn of the century, there was a significant discrepancy between estimations and actual catches of pollock in the West Bering Sea fishing zone: in 1996 – 2001, the TAC realization made 62 – 128%, proving inadequacy of the then predominant perception of the northern stock.

Necessity for rationalization of the northern pollock fishery and addressing of the international management issues emerged with delimitation of the North Bering Sea waters between Russia and the US has called for determination of the northern Bering Sea pollock population structure.

According to the traditional perception of a population (a minimum self-reproducing unit of individuals of the same species which have been inhabiting a certain area for a long period of evolution and which have developed an independent genetic system and their own environment), appearance and development of a population are determined by environment condition and place in ecosystem. The principal prerequisite to formation of an independent population is development of a certain temporally and spatially stable dwelling conditions different from those in adjacent areas. With time, an area with such conditions could become a habitat for an independent population named a statio. It is reasonable, therefore, to start any population research with considering the physical environment. In case of hydrobionts, this is water masses. The first argument that an independent population of hydrobionts could exist in a certain area is presence of quasi-stationary dwelling conditions within this area.

The habitat zonality determines irregularity in the species' spatial distribution. Identification of such intermittence both on the seasonal and interannual scales proves existence of conditions for formation of isolated between fish schools.

Dependent on species biology and the degree of the population structurization, the spatial isolation of groupings could happen not at all periods of the annual cycle or not at all ontogenesis stages. Isolation during the reproduction period is especially important for formation of a new population, because one of its essential prerequisites is existence of a self-reproducing stock consisting of individuals which generally mate with members of the same stock (Mina, 1980).

Specific conditions of certain spawning grounds make basis for formation of abundant year classes, which vary between neighboring populations. Ultimately, abundance of year classes determines a unique size-at-age structure of a population.

A long and relatively secluded existence of individuals within a certain biotope results in development of special biological features and adaptations, including physiological ones which allow individuals to survive and populations to remain stable in the changing environment (Shatunovsky, 1980); the individuals develop phenological markes; inevitably, a directional selection of some useful features and accumulation of random mutations start and lead to development of genetic peculiarities.

If a fish group has all the above mentioned features (i.e. it is relatively isolated in its area of distribution and reproduction; it has a particular size-at-age structure, biological features, adaptations, as well as phenological and genetic markers) we could definitely state that such group represents an independent population and has its unique place and role in the ecosystem, and in particular in fish communities.

In this paper devoted to studying of the pollock population structure in the North Bering Sea, the authors followed the above-mentioned order and at each stage of the study they tried to apply a whole set of approaches to population studies, including genetic, ecological (biogeocenosis), morphological, biochemical, physiological, geographical, energy, and ethological approaches.

The major difficulty in identifying the pollock population structure is associated with the species' high seasonal and ontogenetic migration activity, which varies considerably on the interannual scale dependent on climate/ oceanic conditions, abundance of the given population, and the species itself.

Traditional field studies include either single surveys or single surveys which are made once every two or three years. Following the long-term practice, surveys in the Bering Sea are conducted during the feeding period when the North Bering Sea well developed shelf occupies pollock of the local origin, as well as pollock from the western and eastern spawning grounds. Obviously, there are difficulties in interpreting results of such surveys with application of any technique of the population analysis.

Consequently, in order to obtain reliable scientific data which would give reasonable confidence in division of aggregations formed by fish of different genesis as well as in identification of their belonging to concrete population we should develop a new research methodology.

Traditional technique of studying marine fish migrations which yields most reliable results is mass tagging. However, its major shortcoming is a low recover of tags, especially during studies of straddling stocks which inhabit Exclusive Economic Zones (EEZs) of several states.

The only alternative or supplement to this technique could be performance of repeated surveys in the course of the year. The obtained observations would allow us to follow migrations of major fish aggregations in various periods of the annual cycle: from spawning grounds to feeding areas and then to wintering grounds which are left for spawning grounds again. Even if individuals from different populations mix during the feeding period, surveys made in the spawning and postspawning periods would allow to analyze fish of different genesis and divide mixed feeding aggregations in accordance with the identified peculiarities. To obtain comprehensive information, studies should carry out fully and include the following types of work: trawl surveys, echointegration trawl surveys, zooplankton surveys, spring ichthyoplankton surveys, recruitment trawl surveys, and genetic sampling during the spawning period. Only multiple surveys made in the course of the year would reveal the pollock stock structural pattern in dynamics (Fig. 1).

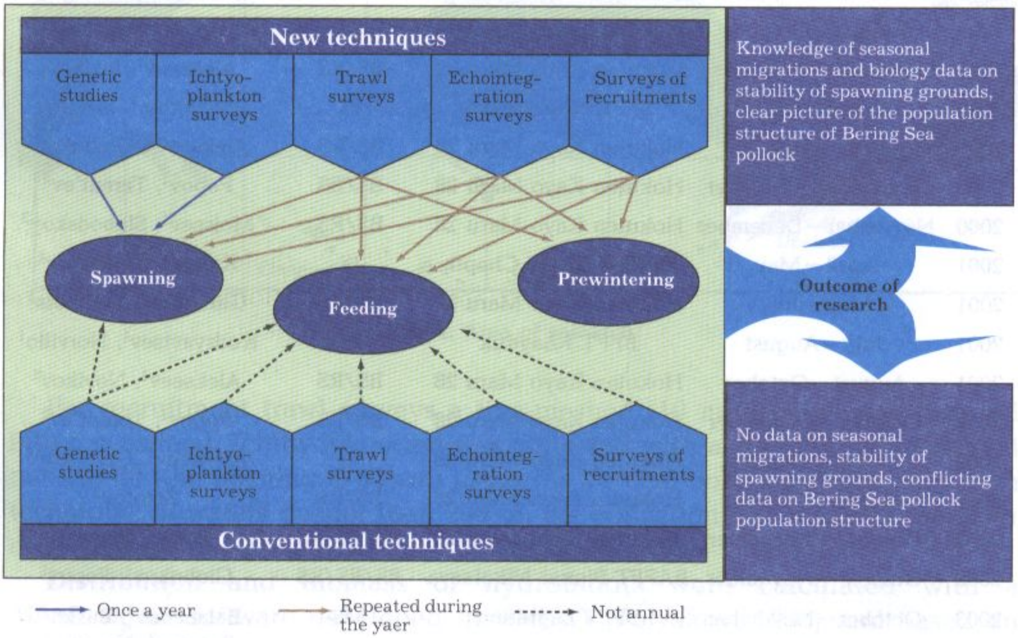

**Fig. 1.** Chart of methods to study the North Bering Sea pollock

Material for the present study was collected in 1996–2004 when 26 cruises to the North, West, and East Bering Sea were made to carry out 21 trawl surveys, 11 echointegration trawl surveys, 8 recruitment trawl surveys, and 5 ichthyoplankton surveys (Table 1).

**Table 1.** List of cruises and types of work the results of which were used

| Year | Month | Type and name of the vessel | Types of work | Scientific observers |
|---|---|---|---|---|
| 1996 | July – September | Hokuten Eiku-Maru 75 | BS/ZS/IS* | Glubokov[1], Maslennikov[1] |
| 1996 | July – September | Hokuten Kasima-Maru 8 | BS/ES | Goncharov, Kochkin[1] |
| 1996 | October – November | Hokuten Eiku-Maru 75 | BS/ES | Bulanov[1], Norvillo[1] |
| 1996 | December | Hokuten Eiku-Maru 75 | BS/ES | Norvillo[1] |
| 1997 | June – August | Hokuten Eiku-Maru 75 | BS/ES | Glubokov[1], Ukolov[1] |
| 1997 | August – October | Hokuten Eiku-Maru 75 | BS/ES | Goncharov[1], Naumenko[2] |
| 1998 | June – October | Hokuten Kayo Maru 28 | Identification of the main aggregations' boundaries | Glubokov[1] |
| 1998 | October – December | Hokuten Kayo Maru 28 | BS/ES | Alekseev[1], Goncharov[1] |
| 1999 | June – August | Hokuten Kayo Maru 28 | BS/RS | Bizikov[1], Glubokov[1] |
| 1999 | August – October | Hokuten Kayo Maru 28 | BS | Bonk[2], Fedorets[3] |
| 1999 | November – December | Hokuten Kayo Maru 28 | BS/RS | Alekseev[1], Bizikov[1] |
| 2000 | April – May | SFFT Novokievka | IS | Privalikhin[1], Startsev[3] |
| 2000 | June – August | Hokuten Kayo Maru 28 | BS/RS | Alekseev[1], Glubokov[1] |
| 2000 | September – October | Hokuten Kayo Maru 28 | BS/ES | Popov[1], Terent'ev[2] |
| 2000 | November – December | Hokuten Kayo Maru 28 | BS/RS | Moiseev[1], Slobodskoy[3] |
| 2001 | April – May | BFFT Nikolay Chepik | IS | Kireev[2], Khodakov[1] |
| 2001 | May – July | Hokuten Kayo Maru 28 | BS/RS | Glubokov[1], Fedorets[3] |
| 2001 | July – August | BFFT Khayduk | IS | Kudryavtsev[1], Norvillo[1] |
| 2001 | August – October | Hokuten Kayo Maru 28 | BS/RS | Alekseev[1], Novikov[2] |
| 2001 | October – December | Hokuten Kayo Maru 28 | BS/ES | Popov[1], Terent'ev[2] |
| 2002 | March – April | Hokuten Kayo Maru 28 | IS | Alekseev[1], Glubokov[1] |
| 2002 | August – October | Hokuten Kayo Maru 28 | BS/RS | Zolotov[2] |
| 2002 | October – December | Hokuten Kayo Maru 28 | BS/ES/RS | Bonk[2], Popov[1] |
| 2003 | October – November | BAFFT Pioner Nikolaeva | BS/ES/RS | Glubokov[1], Popov[1] |
| 2003 | October – November | SFFT Bagration | MS | Balabanov[4], Buslov[2], Zolotov[2], Norvillo[1], Khodakov[1] |
| 2004 | February – March, June – July | R/V Miller Freeman | ES | Williamson[5], Glubokov[1], Nikolaev[3], Stepanenko[3], Khonkalekntо[5] et al. |

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*Note:* *BS – bottom trawl survey; ZS – zooplankton survey; IS – ichthyoplankton survey; ES – echointegration trawl survey; RS – recruitment trawl survey; MS – midwater trawl survey.

*Scientific observers:* [1]All-Russia Research Institute of Fisheries and Oceanography (VNIRO, Russia);

[2]Kamchatka Research Institute of Fisheries and Oceanography (KamchatNIRO, Russia);

[3]Pacific Fisheries Research Center (TINRO-center, Russia);

[4]Institute of the Sea Biology FEA RAS (ISB, Russia);

[5]Alaska Fisheries Science Center (AFSC, USA).

Figure 2 illustrates the surveyed area. All types of surveys were made in accordance with the station grid (Fig. 3–5).

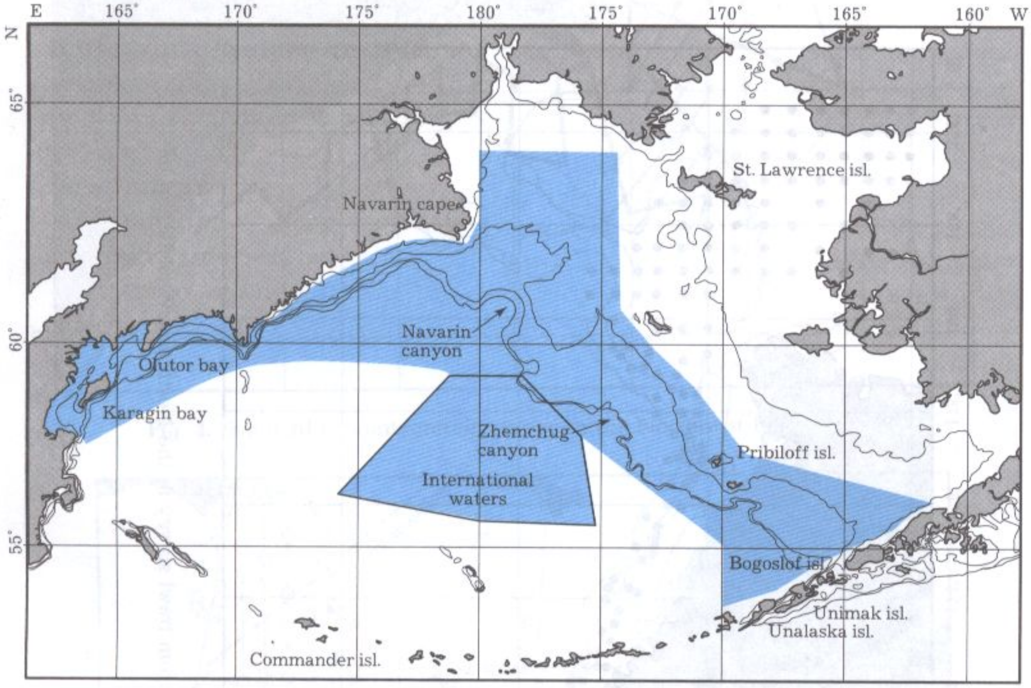

**Fig. 2.** Area of research

For recruitment trawl surveys a fine-meshed (10 mm) panel was inserted into the codend. Ichthyoplankton was collected with a standard cone-shaped net IKS-80 (the opening Ø 80 cm) using the vertical bottom-surface collection technique; in waters deeper than 200 m, the collection was made in the layer of 0–200 m.

Distribution and biomass of hydrobionts were calculated with a *MapDesigner* software developed in VNIRO (Polyakov, 1996) and based on the method of spline–approximation (Ivanov, Stolyarenko, 1988). The following variables and coefficients were used in the calculations: trawling velocity – 4 knots; spline smoothing – 0; coefficient of depth impacts – 1000.

Studies of genetic divergence in pollock aggregations were based on the nucleotide sequences of genome DNA analysis including microsatellite loci.

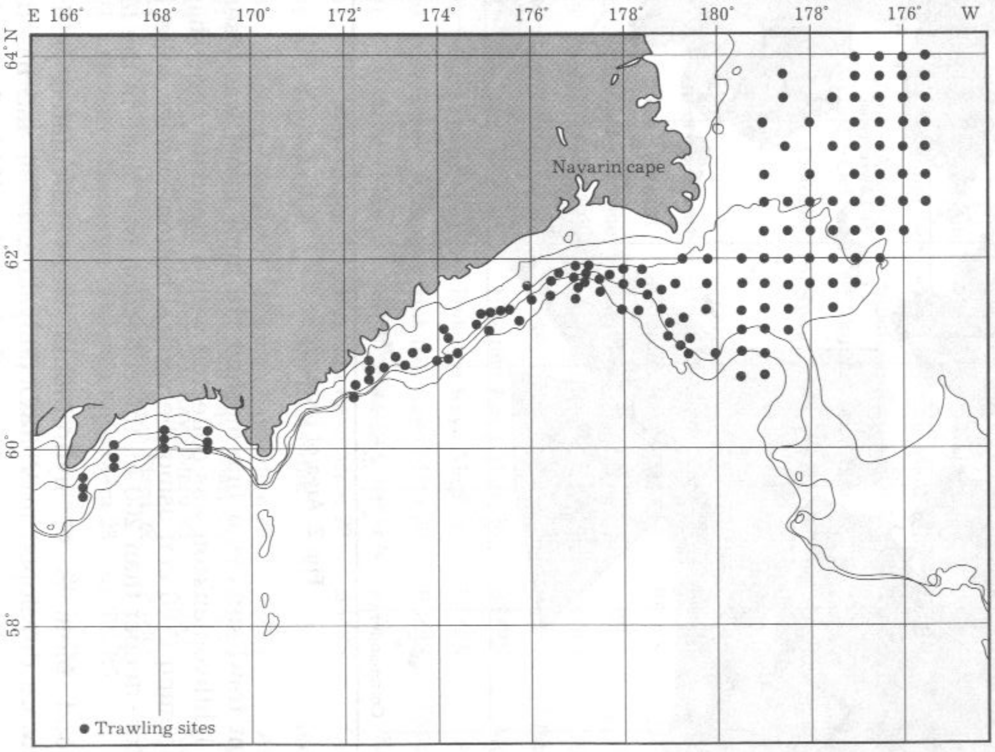

Fig. 3. Standard bottom trawl survey in the North and West Bering Sea

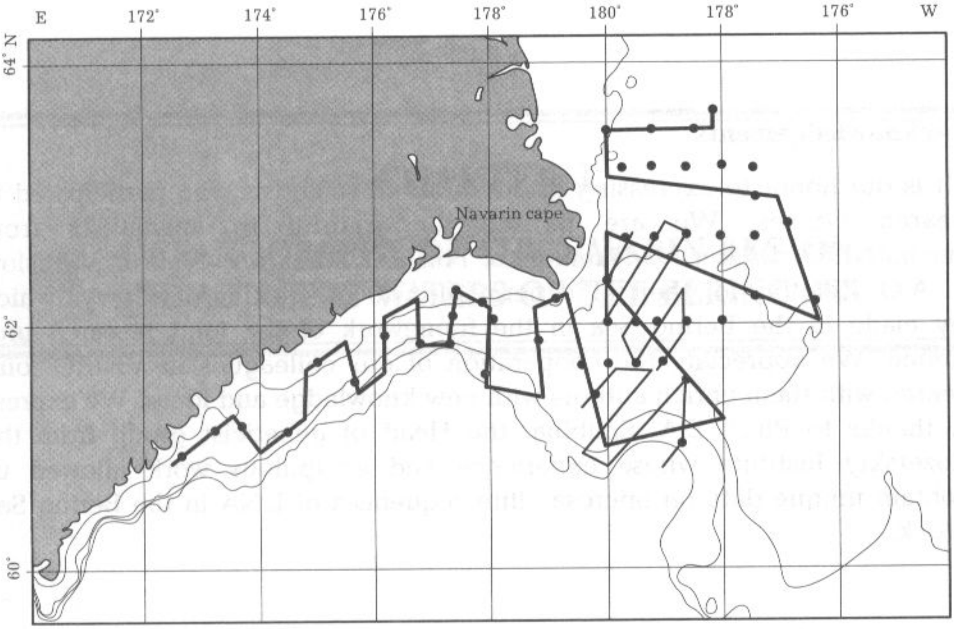

**Fig. 4.** Standard echointegration survey in the Northwest Bering Sea

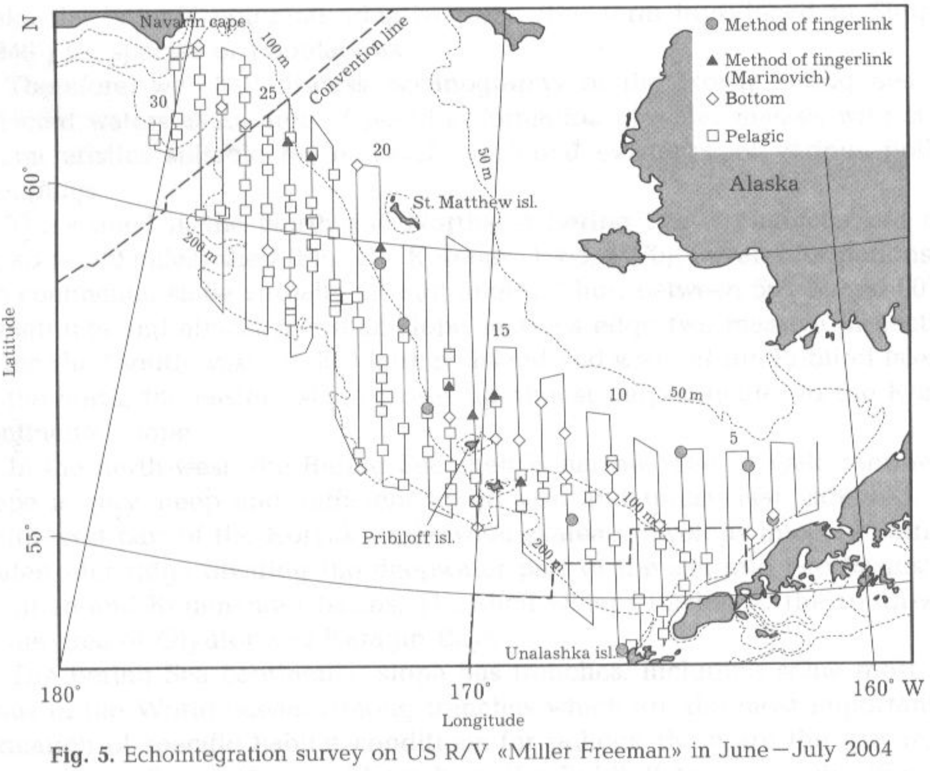

**Fig. 5.** Echointegration survey on US R/V «Miller Freeman» in June – July 2004

## Acknowledgements

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# CHAPTER 1

## OCEANOGRAPHY OF THE NAVARIN REGION AND ADJACENT WATERS OF THE BERING SEA

The degree of the species structurization is, *inter alia*, more deep if its habitat is more diverse. Quasistationary features of the physical environment could make the latter a potential adaptive zone (the term introduced in Simpson (1948)) for species or populations.

Therefore, we shall discuss oceanography of the North Bering Sea and adjacent waters as an area of possible formation of water masses with stable characteristics suitable for relatively secluded existence of various pollock groupings.

The seabed in the North and Northeast Bering Sea is characterized by a broad (≈ 300 miles) shelf (Fig. 1.1, Kotenev, 1965, 1970). Several formations cut the continental slope virtually at right angles. Thus, between 56° N and 60° N, sublatitude and almost meridian slope sections edge two massive projections of the shelf south-west off St. Matthew Island and west off the Pribiloff Islands. In the north, the eastern slope closes up almost perpendicular to the Koryak continental slope.

In the north-west, the Bering Sea shelf is narrow. The Koryak continental slope is very steep and sufficient lengthwise and transversal indented. The south-west part of the Koryak underwater plateau develops into the Shirshov underwater ridge dividing the deepwater part of the sea into two basins: the Aleutian and Kommandor basins. The shelf widens further to the south-west, in the area of Olyutor and Karagin Bays.

The Bering Sea continental slope has trenches, including some most spacious in the World ocean. Among trenches which are the most important for formation of specific habitat conditions for pollock there are the Vityaz, the Navarin, the Pervenets, the Zhemchug, the Pribiloff trenches, etc. (Fig. 1.1, Kotenev, 1965, 1970).

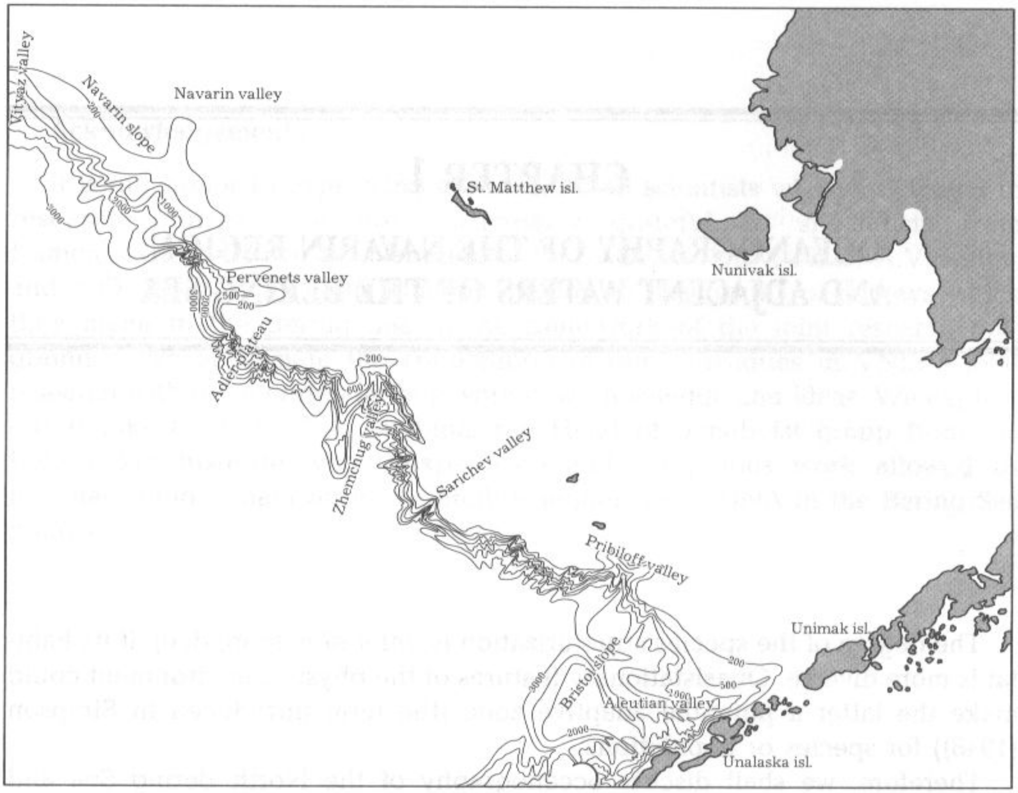


Fig. 1.1. Bathymetric scheme of the North and East Bering Sea (Kotenev, 1970)

The following regions can be identified on the base of bathymetric peculiarities of the shelf and continental slope: the Karagin-Olyutor, Koryak, Navarin, St. Matthew, and Pribiloff regions. Trenches and ridges generally form natural borders of these regions.

The cumulative effect of the bottom topography, water inflows and winds creates a complex system of the Bering Sea currents. The greatest inflow of oceanic water masses to the Bering Sea comes through the Amchitka and Blizhni straits (Reed, Stabeno, 1999). Joining the Attu current, these waters continue along the slope and form the Bering Sea slope (BSS) current (Stabeno, Reed, 1994; Reed, 1996). This current is characterized by a low transport velocity and division into two or more streams. Complex topography of the eastern slope causes formation of numerous eddies (Ø 20 – 100 km) which attain horizons of 400-1000 m (Natarov, 1963; Kinder et al., 1975; Schumacher, Reed, 1992; Schumacher, Stabeno, 1994; Cokelet, Stabeno, 1997; Stabeno et al., 1999) and development of local peculiarities of currents, e.g. between the Aleutian and Pribiloff trenches, from the Pribiloff trench up to the Zhemchug one, and between the latter and the Navarin trench (Khen, 1989;

Kotenev, 1995). Trenches accommodate quasistationary eddies which slow down the north-western transport of water masses along the outer shelf and slope and set natural boundaries around statios and biotopes (Kotenev, 1995). Above the trenches the perturbed flow forms a cyclonic meander resulting in upwelling of nutrient-rich bottom waters (Fig. 1.2, 1.3; Markina, Khen, 1990; Verkhunov, 1995; Schumacher, Stabeno, 1998), which creates well-defined zones of high productivity.

In the north, the BSS current divides into the east and west branches (the Navarin and Kamchatka currents, respectively). The Navarin current heads for Anadyr Gulf to create an anticyclonic eddy (Fig. 1.4) (Khen, Voronina, 1986; Khen, 1988; Reed, Stabeno, 1993; Reed et al., 1993; Bond et al., 1994; Cokelet et al., 1996; Khen, 1999; Maslennikov et al., 1999; Gidrometeorologiya i gidrohimiya morei, 2001). Within the Gulf the current velocity does not exceed 4 cm/s. Waters with elevated primary production form a belt stretching in the direction of the Chukchi Sea and resembling the Navarin current configuration. Therefore, this current plays a very important role in maintaining high productivity of the North Bering Sea shelf waters (Khen, 1999). The Kamchatka current has a higher velocity than the BSS one, attaining 15—20 cm/s near the Kamchatka Strait (Khen, 1989; Markina, Khen, 1990; Tsyban', 2000;). Water circulation along the Koryak coast represents a system of alternate eddies of different signs, which phormed the water transport along the outer shelf parallel to the Kamchatka Strait (Fig. 1.5; Verkhunov, 1995).

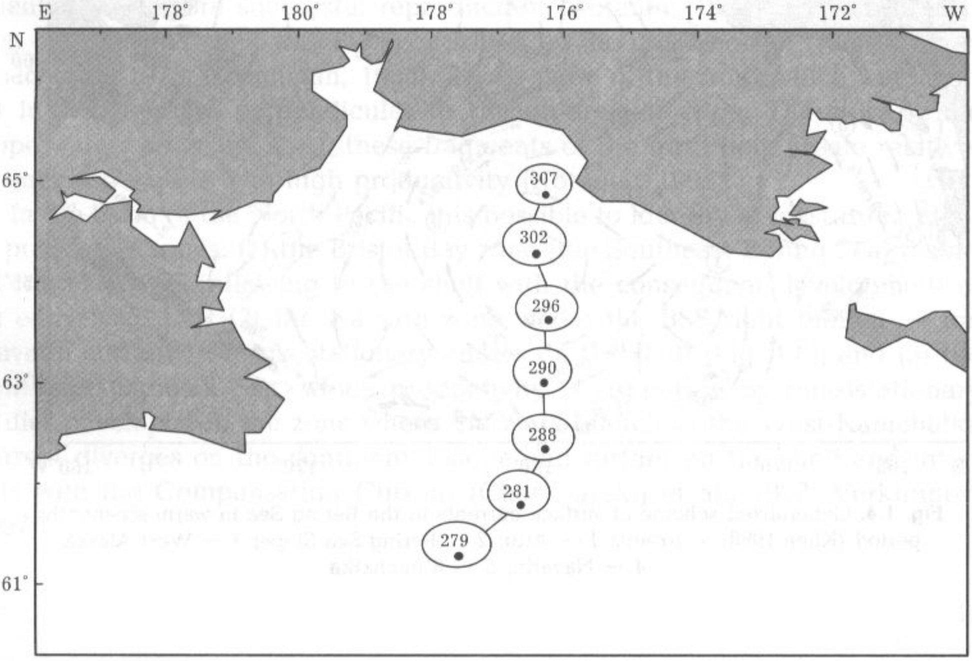


**Fig. 1.2.** Position of stations in survey from «Mlechny Put'» in June 1990 (Verkhunov, 1995)

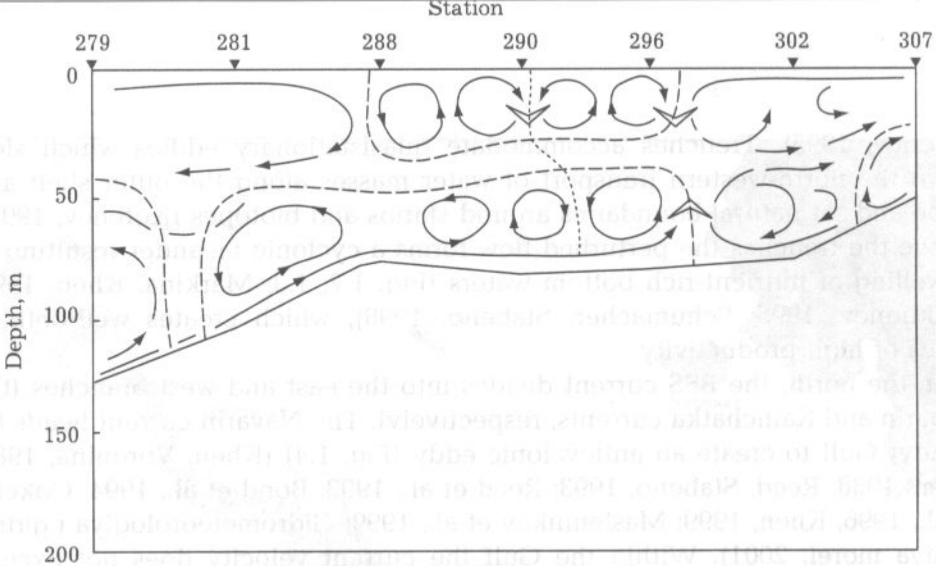


**Fig. 1.3.** Scheme of crosswise water circulation in Anadyr Bay in June 1990 (Mlechny Put' survey data; Verkhunov, 1995)

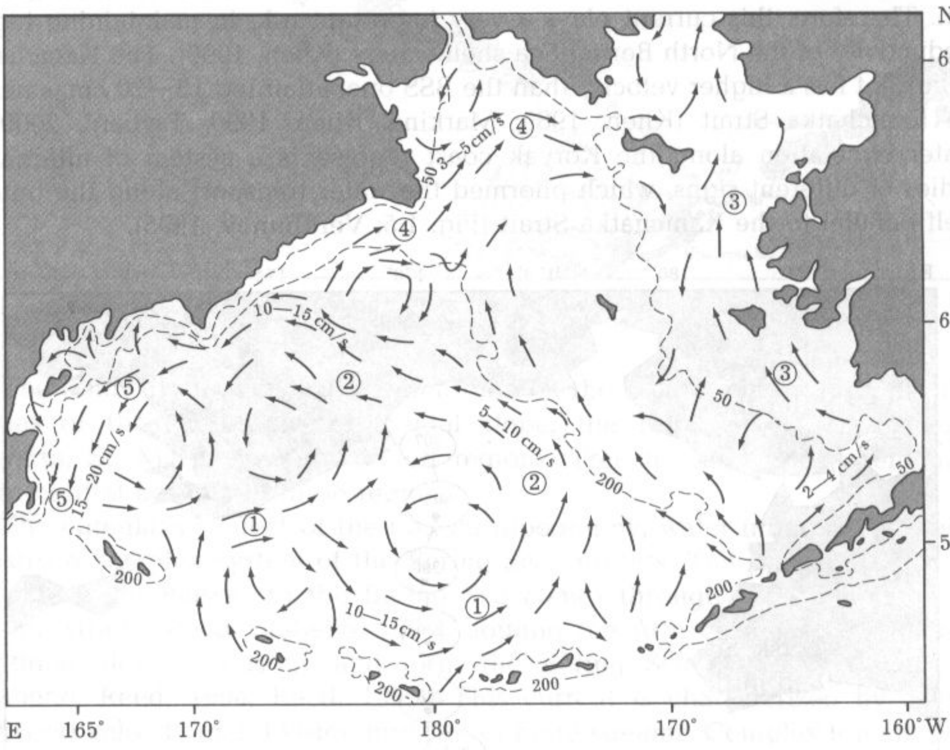


**Fig. 1.4.** Generalized scheme of surface currents in the Bering Sea in warm six-months period (Khen,1988). Currents: *1* – Attu; *2* – Bering Sea Slope; *3* – West Alaska; *4* – Navarin; *5* – Kamchatka

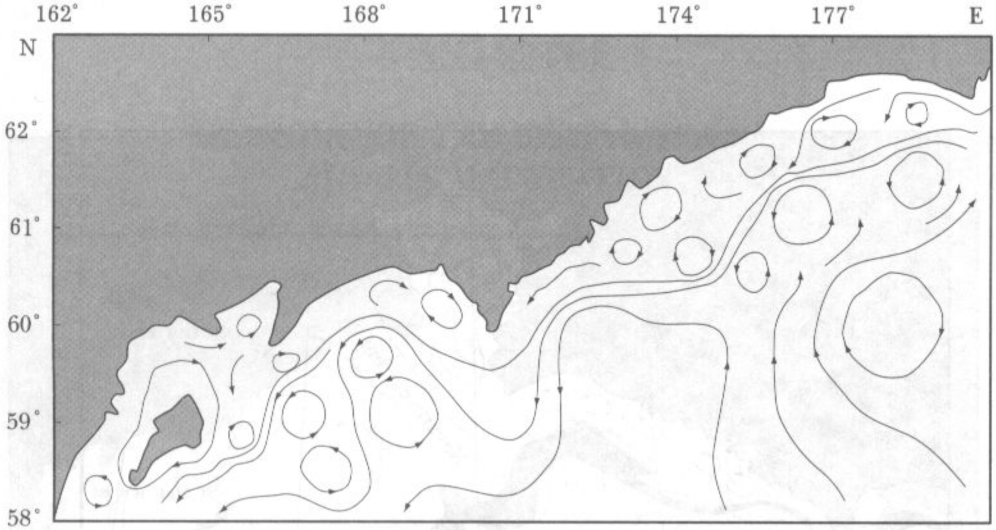


**Fig. 1.5.** Scheme of surface currents in the West Bering Sea, October – November, 1990 (Verkhunov, 1995)

Interaction of the oceanic (slope) and shelf (outer shelf) waters is an essential factor providing seclusion for individual units of the fish stocks. This interaction could have a completely different impact on the reproduction success depending on the direction of the water transport: when shelf and slope waters are transported in the direction of deep-water basins the pollock survival at the early ontogenesis stages declines, while the slope water inflow to the shelf provides favorable conditions for development of eggs and larvae and, consequently, for a more successful reproduction (Kotenev, 1995). Lateral interaction of slope and shelf waters is controlled by the outer-border front (Kinder, Coachman, 1978; Coachman, 1986). Those parts of the front which are located in trenches are perpendicular to the outer-shelf edge. Therefore, when slope waters enter the shelf, these fragments of the front help create relatively enclosed waters with high productivity (Kotenev, 1995).

In the basin of the North Pacific it is possible to identify at least three highly productive zones: (1) the Bristol Bay zone (the Southeast Bering Sea) resulted from the BSS inflowing to the shelf with the consequent development of an eddy (Fig. 1.4); (2) the Navarin zone where the BSS right branch – the Navarin current – forms stationary eddies on the shelf (Fig. 1.6); and (3) the Southeast Okhotsk Sea, which productivity is supported by quasistationary eddies developed in the zone where the main branch of the West-Kamchatka current diverges on the continental slope and further on the shelf and interacts with the Compensating Current (Chernyavskij et al., 1993; Verkhunov, 1997).

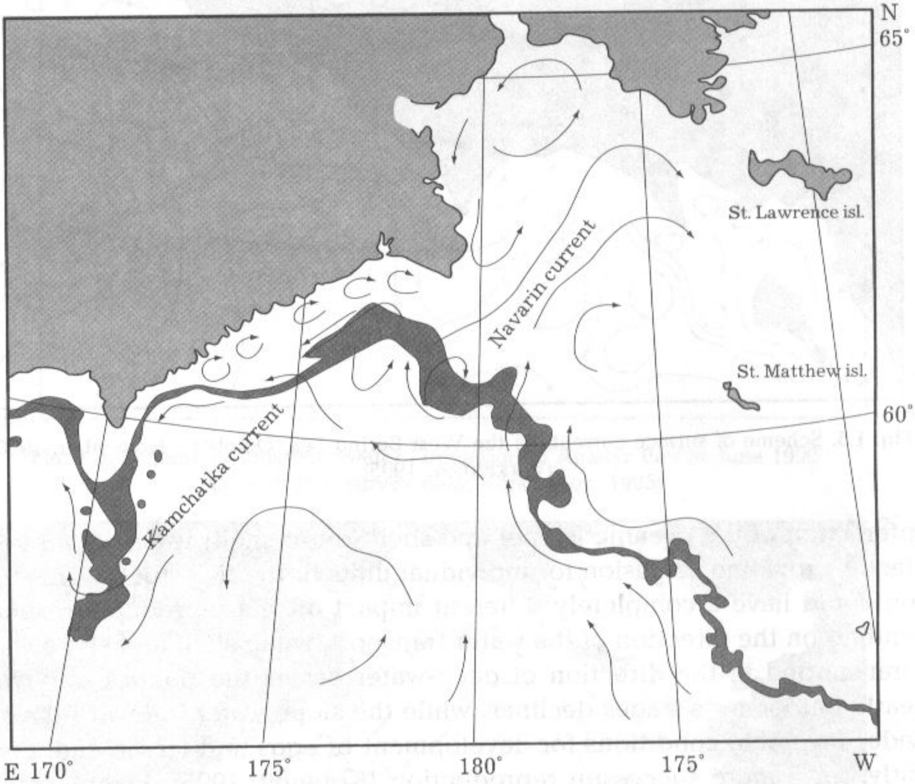


**Fig. 1.6.** Scheme of currents in the North Bering Sea in summer 1996–1997 (plotted by V. Maslennikov)

The functioning of the Bering Sea byota is closely related to the vertical structure of the water masses. The Bering Sea water masses are characterized by the west subarctic structure with a cold intermediate layer in summer and warm intermediate water masses underlying the cold ones (Natarov, 1963; Arsen'ev, 1967). In the north there are two nucleuses of cold: one is in the center of the northern shelf (the St.Matthew–St.Lawrence shallow waters and Krest Inlet within Anadyr Gulf) with negative values of the water temperature in the cold intermediate layer; and the other is in the Karagin region (Fig. 1.7) (Khen, 1988).

The rate and location of the cold nucleuses have a significant impact on formation of the biotope peculiarities as well as on reproduction and distribution of the Bering Sea hydrobionts.

Bottom sediments, which reflect, *inter alia*, the pattern of the hydrological regime could be selected as a significant indicator of development of specific conditions of statios and biotopes. In the North Bering Sea and adjacent waters it is possible to identify the following major mineral sediment macro-

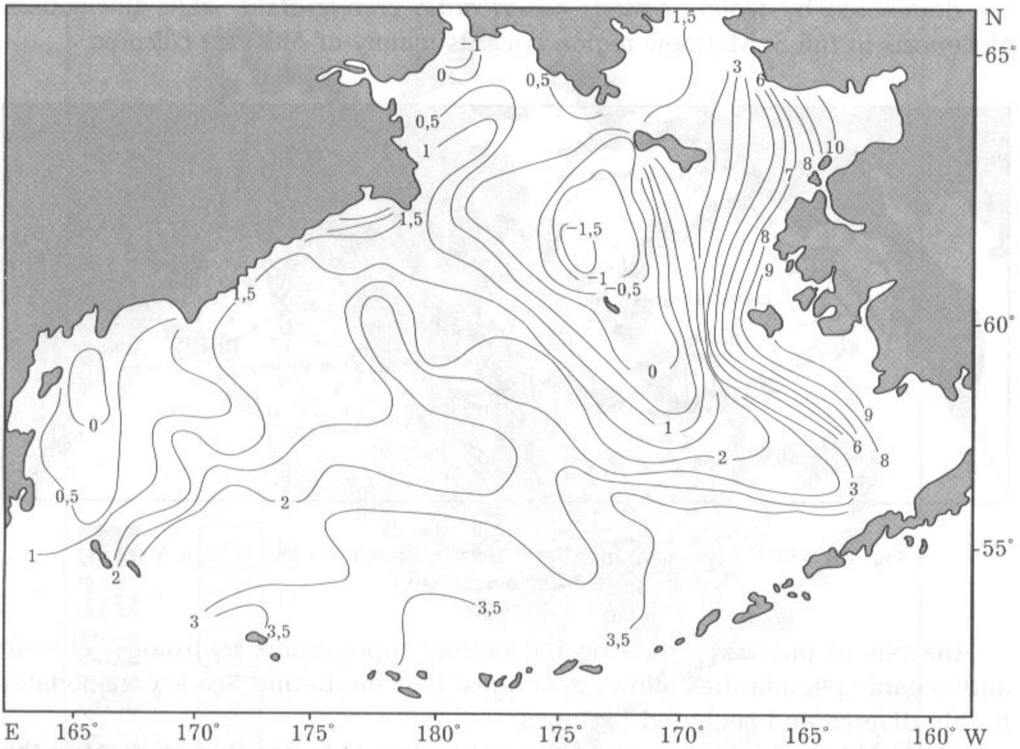


**Fig. 1.7.** Pattern of cold intermediate layer nucleus in the Bering Sea in August (Khen, 1988)

provinces: the East Bering Sea, the North Bering Sea, the Koryak region, the Shirshov ridge, and the Kamchatka region (Fig. 1.8) (Gershanovich, 1970).

In its turn, distribution of nutrients in the feeding zones depends on the degree of the bottom waters mobility and intensity on sedimentation. Therefore, there is a clear association of biocenoses prevailing of various trophic groups with, firstly, zones of contiguity of various water masses and bottom; and secondly, with certain types of sediments. Narrow shelves of the West Bering Sea and the East Kamchatka are characterized by high mobility of waters and, consequently, accommodate no biocenoses accustomed to a high degree of silting. As a result of shift of the intensive sedimentation zone to the upper slope the shelf itself is dominated by biocenoses consisting mainly of species which filter seston from the bottom layer. On broad shelves there are spacious zones of intensive sedimentation, which provide dwelling for species collecting detritus from the bottom surface (Neiman, 1963). Distribution of biocenoses (Fig. 1.9; Neiman, 1963) demonstrates a definite similarity of biocenoses in the Navarin region and Bristol Bay; these biocenoses are dominated by *Ophiura sarsi, Venericardia crebricostata,* while the bottom biocenosis in the St.Matthew region consists mainly of *Macoma calcarea.*

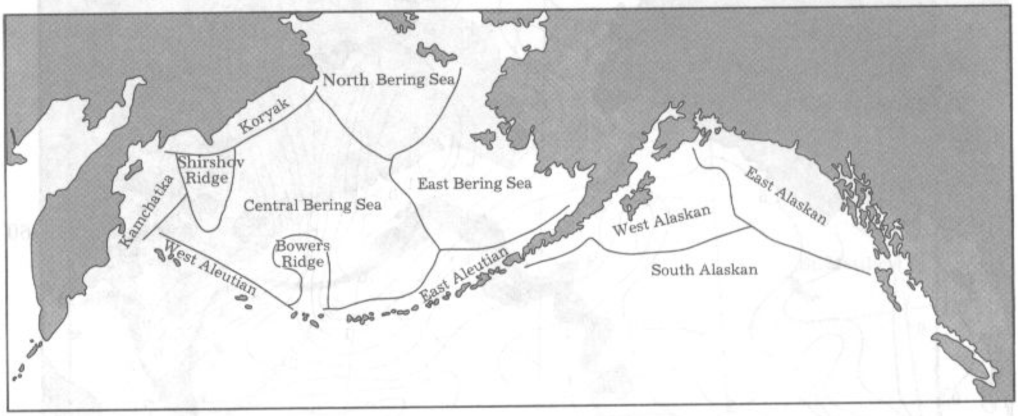


**Fig. 1.8.** Mineral sediment macroprovinces in Bering Sea and Gulf of Alaska (Gershanovich, 1970)

Analysis of published data on the bottom topography, hydrology, climate and oceanic peculiarities allows to suggest that the Bering Sea accommodates highly diverse and secluded biotopes.

In the North Bering Sea and adjacent waters it is possible to identify the following areas with specific climate and oceanic features:

– the Olyutor-Karagin region in the vicinity of Ozernoe Inlet, the Kamchatka current leaves the slope to turn eastward and then northward and forms an eddy with a large diameter;

– the Koryak region (characterized by the rapid Kamchatka current, narrow shelf, and transport of water masses along the outer shelf parallel to the Kamchatka current);

– the Navarin region (the structure of local waters is determined primarily by inflow of the Navarin current and the consequent formation of spatially and temporally stable eddies due to the bottom topography);

– the St. Matthew region (local shallow waters and absence of distinct currents cause formation of a stagnant zone and one of the largest nucleus of cold);

– the Pribiloff region located northward of the Pribiloff Islands (the structure of local waters is determined by the BSS current and presence of two large trenches, the Pervenets trench and the Zhemchug trench);

– the Unimak-Bristol region (similar to the situation in the Navarin region, the local bioproductivity is associated with water masses which enter the shelf in the north-east direction).

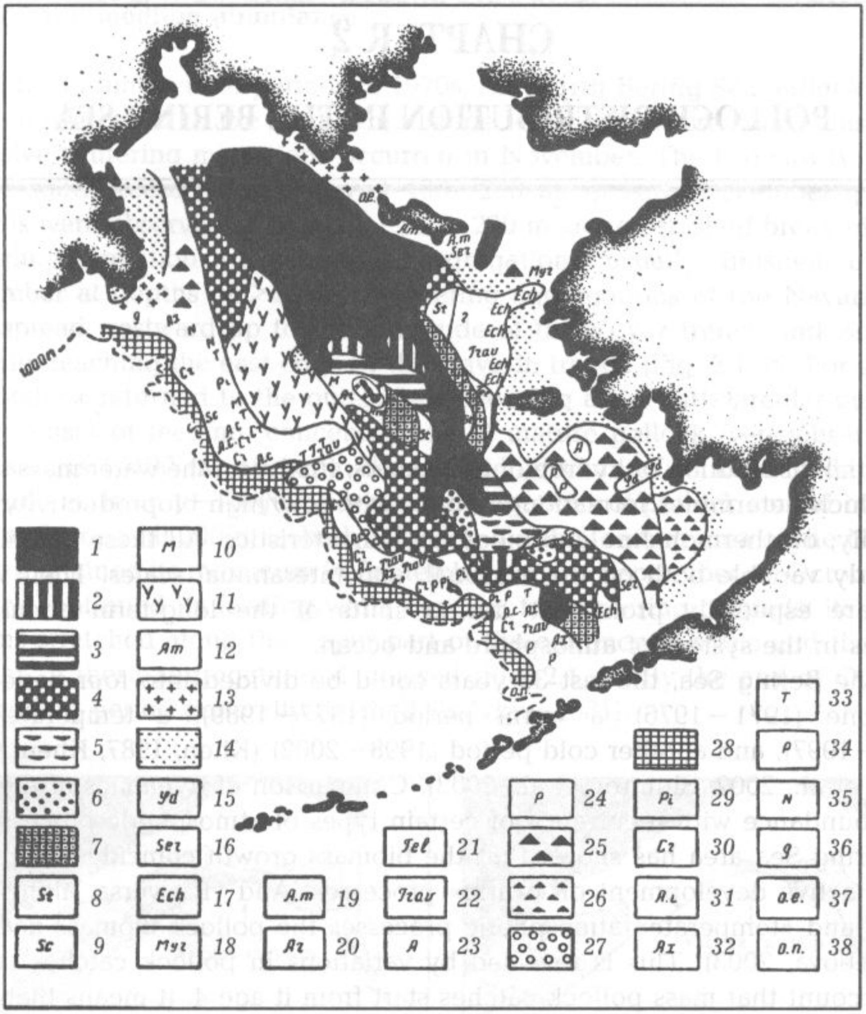


**Fig. 1.9.** Distribution of biomasses in North and East Bering Sea:
*1 — Macoma calcarea; 2 — Leda pernula; 3 — Yoldia hyperborea; 4 — Ophiura sarsi; 5 — Cucumaria calcigera; 6 — Cardium ciliatum; 7 — Nucula tenuis; 8 — Sternaspic scutata; 9 — Scoloplos armiger; 10 — Maldane sarsi; 11 — Yoldia traciaeformis; 12 — Ampharete acutifrons; 13 — Spongia + Hydroidea + Bryozoa, 14 — Echinarachnius parma; 15 — Idanthirsus armatus; 16 — Serripes groenlandicum; 17 — Echiurus echiurus alaskanus; 18 — Myriochelle oculata; 19 — Ampelisca macrocephala; 20 — Artacama proboscidea; 21 — Tellina lutea; 22 — Travisia forbesii; 23 — Astarte borealis; 24 — Praxilella gracilis; 25 — Venericardia crebricostata; 26 — Spisula polynima voyi; 27 — Chiridota ochotensis; 28 — Laonice cirrata, Ophiura leptoctenia, Brisaster latifrons; 29 — Pista cristata; 30 — Crenella columbiana; 31 — Ampelisca catalinensis; 32 — Axiothella catenata; 33 — Terebellides stroemi; 34 — Pontarpinia longirosris; 35 — Nicomache lumbricalis; 36 — Golfingia margaritacea; 37 — Ophelia limacina; 38 — Ophiopthalmus normani* (Neiman, 1963)

# CHAPTER 2

## POLLOCK DISTRIBUTION IN THE BERING SEA

Spatial distribution of hydrobionts depends, firstly, on the water mass structure which determines formation of zones with low/high bioproductivity; and secondly, on thermohaline and biogenic characteristics. All these parameters are fairly variable both on the seasonal, and interannual scales. Their variations are especially prominent during shifts of the long-term circulation regimes in the system of atmosphere and ocean.

In the Bering Sea, the last 35 years could be divided into four periods: a cold one (1971 – 1976), a warm period (1977 – 1989), a temperate one (1990 – 1997), and another cold period (1998 – 2002) (Khen, 1987; Khen, 1989; Borets et al., 2002; Shuntov et al., 2003). Comparison of dynamics of the pollock abundance with recurrence of certain types of atmospheric processes in the Bering Sea area has shown that the biomass growth coincides with periods of active development of «warm» processes. And vice versa, along with «cold» and «temperate» atmospheric processes the pollock biomass decreases (Glebova, 2003). This is revealed by variations in pollock catches taking into account that mass pollock catches start from it age 4. It means that firstly strong generation is included in catch statistics after 4 year when this generation was born only. In 1974 – 979, the mean annual catch of the Bering Sea pollock totaled 1,524,000 t. In 1980 – 1992, this value increased up to 2,625,000 t. However, in 1993 – 2005, the mean annual catch in the basin decreased again down to 1,856,000 t (Fadeev, Vespestad, 2001; Ianelli et al., 2006; Global capture production 1950 – 2005, 2006).

During periods of high abundance, competition for space and food increases driving some individuals to seek new areas to inhabit, and thus, affecting the spatial distribution. Therefore, we should discuss the pollock spatial distribution separately for periods of a low/medium abundance (the 1970s, the 1990s – the early 21st century) and a high one (the 1980s).

### Low and medium abundance

In the autumn-winter periods of 1970s, **the North Bering Sea pollock** would migrate from shelf to the continental slope to escape severe conditions. Most intensive wintering migrations occurred in November. The fish slowly moved to the south keeping at depths of 100–200 m. In early December, pollock schools were observed at depths of 100–270 m along the shelf break off cape Navarin. Formation of wintering aggregations usually finished by late December at depths of >180 m. Wintering aggregations of the Navarin pollock spread westward up to the longitude of the Vityaz trench and eastward virtually reaching the east edge of the Navarin trench (Fig. 2.1, *c*). For spawning, pollock returned to the outer shelf choosing areas with circular currents. At the onset of feeding, concentrations of mature pollock were observed in shelf waters (<100 m) off cape Navarin, while young fish kept to depths of 140–150 m. In July–August, feeding aggregations of pollock spread over the shelf and slope till 200 m isobath (Fig. 2.1, *a*). The feeding area of the Navarin pollock attained its maximum in September. In late September – October, the species continued its feeding while heading for wintering grounds; its aggregations stretched along the upper part of the continental slope and the overall area of these aggregations decreased (Fig. 2.1, *b*). By the end of October, the feeding period generally finished (Balykin, 1981).

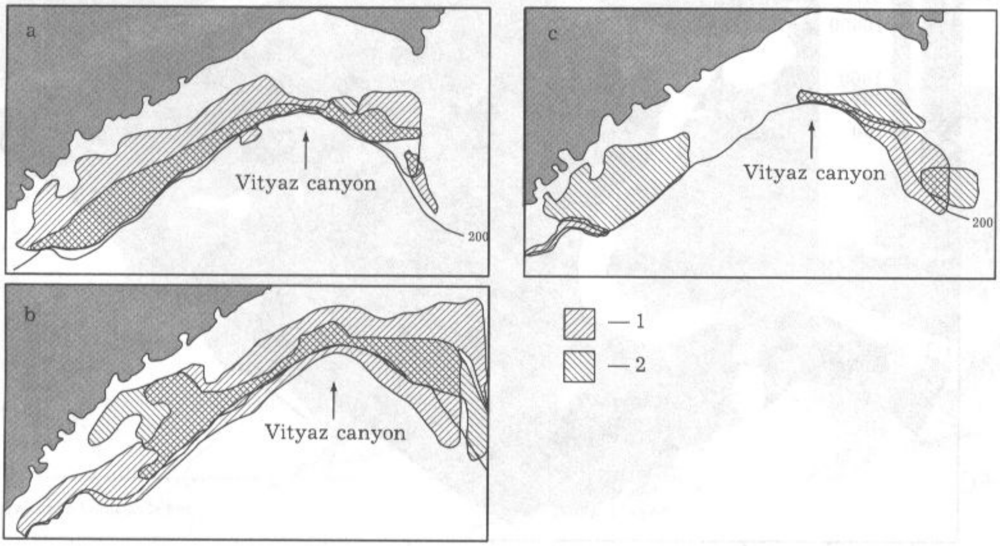


**Fig. 2.1.** Distribution of pollock in Koryak and Navarin areas in the 1970-s: (*a*) – July (1) and August (2); (*b*) – September (1) and October (2); (*c*) – November (2) and December (1) (Balykin, 1981)

The largest part of the year (from October till August) the Navarin pollock shoals are completely detached from its neighbors and only mixes up with the Koryak pollock during one month - September (Fig. 2.1).

Till 1976, the pollock distribution area had been restricted in the north by the Bering Strait. Then pollock was very rarely registered to the north of the 63rd parallel (Walters, 1955; Alverson and Wilimovsky, 1966; Quast, 1972).

During the following period of a relatively low abundance of pollock (the 1990s – the early 21st century), very dense aggregations of pollock in the North Bering Sea were observed since July till December both in the bottom layer, and in the pelagic one, particularly in the area of a quasistationary eddy eastward of the Cape Navarin, in the west slopes of Navarin canyon and in the southwest part of Anadyr Gulf (Radchenko, Feschenko, 1996; Varkentin, 1998; Datskij et al., 1999; Datskij et al., 2000; Datskij, Batanov, 2000; Fadeev, 2001; Balykin, Varkentin, 2002 a; Borets et al., 2002; Kuznetsov et al., 2002; Glubokov, 2003; Fadeev, Gritsai, 2003; Datskij, 2004 a). No abundant concentrations of pollock were found northward of Cape of Providence. In July-October, the western boundary of the north pollock schools ran in the vicinity of the Vityaz canyon, (177° E) (Fig. 2.2, 2.3) (Varkentin, 1998; Borets et al., 2002; Kuznetsov et al., 2002; Glubokov, 2005).

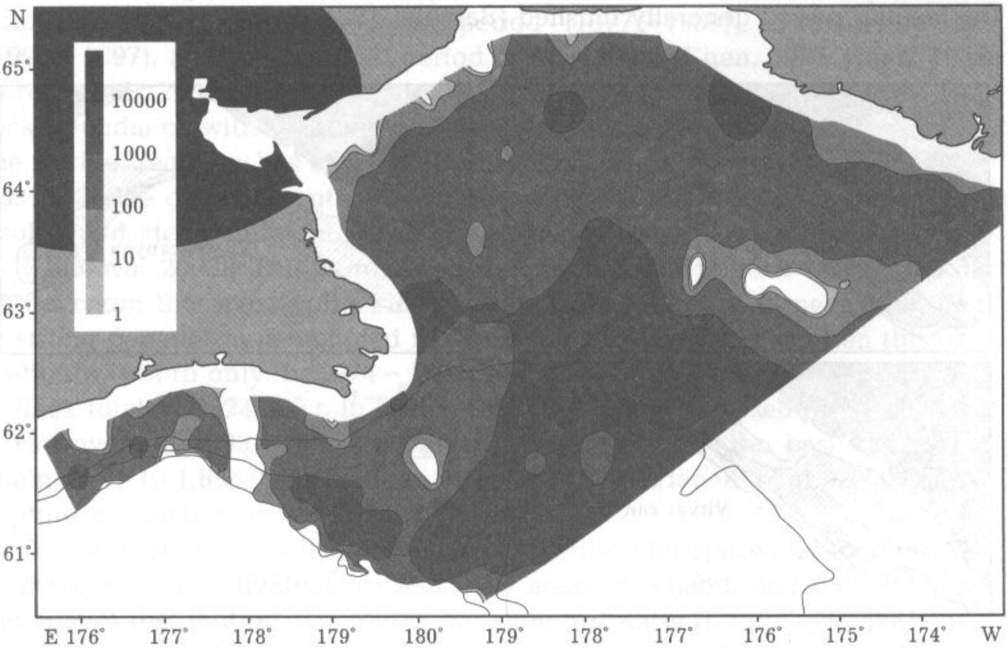


**Fig. 2.2.** Distribution and density (ind/km²) of near bottom concentrations of mature pollock in Navarin area in September – October 1999 (Borets et al., 2002)

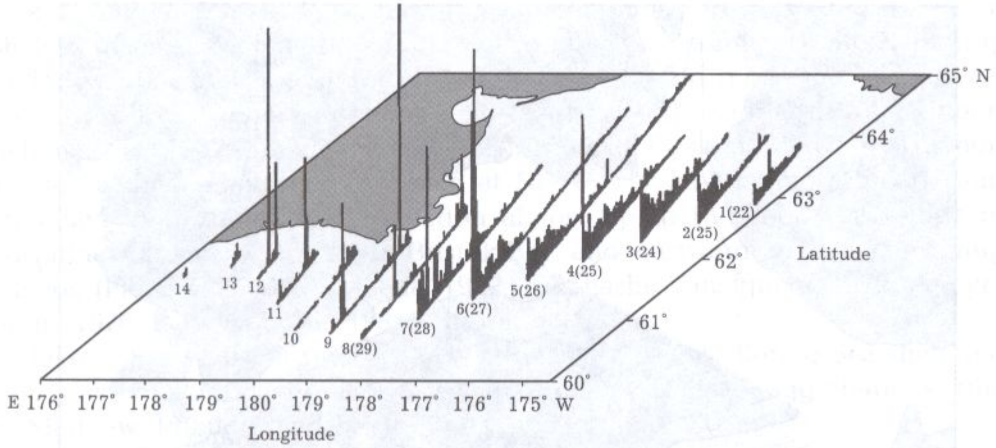
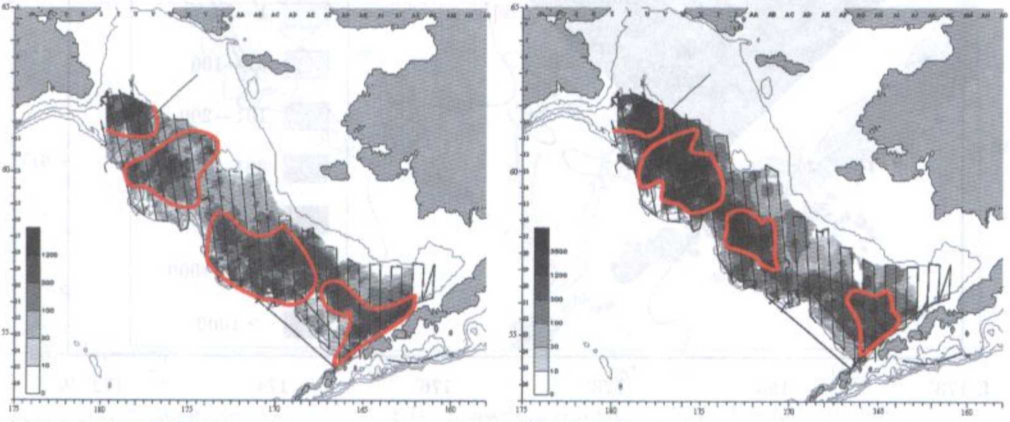


**Fig. 2.3.** Distribution of pollock based on hydroacoustic survey data in September 2000 (Kuznetsov et. al., 2002)

The southeast the Navarin pollock aggregations stretched into the US EEZ as far as ≈60°30′ N, 177°00′ W. (Fig. 2.4, 2.5). In December, pollock moved to the outer shelf and the continental slope (Balykin, Varkentin, 2002 a, Glubokov, 2005). P.A.Balykin and A.I.Varkentin (2002 a) noticed that the Navarin pollock migration to deeper waters in late autumn – early winter correlated with the time of the prespawning aggregation development in other parts of the Bering Sea.



**(a) near bottom layer** **(b) pelagic layer**

**Fig. 2.4.** Distribution of pollock abundance based on the echointegration survey in July 2004 (plotted by A. Nikolaev; boundaries by the authors)

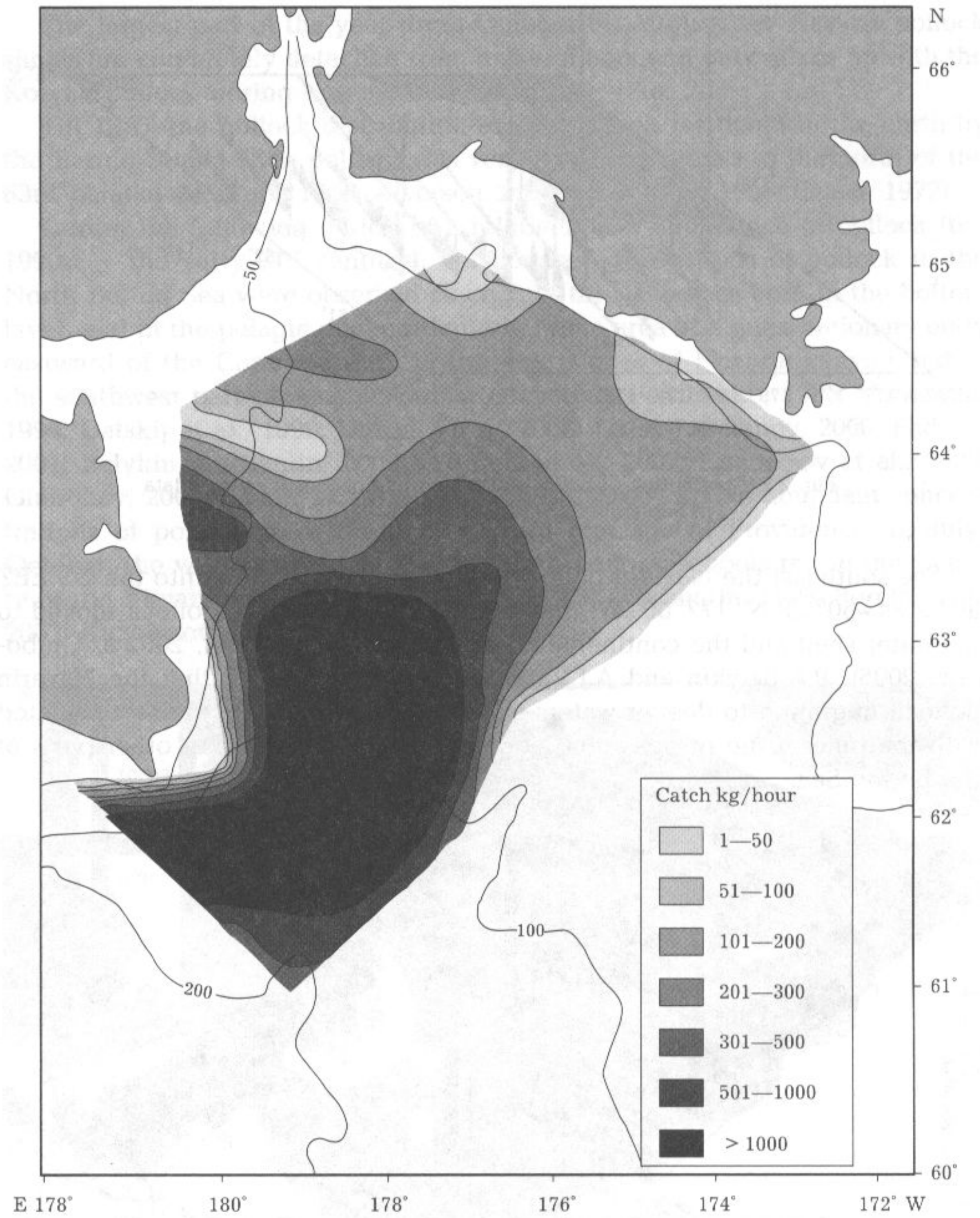
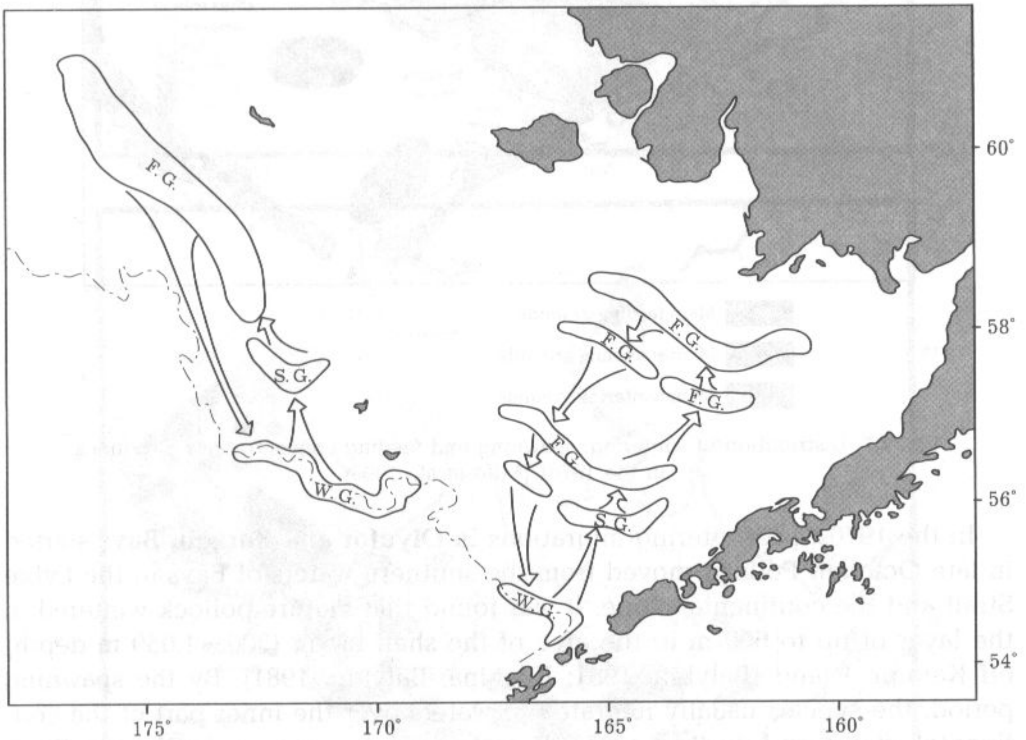


**Fig. 2.5.** Distribution of pollock catches in Navarin area based on the September – October 1995 bottom trawl survey data collected from «Shursha» vessel (Radchenko, Feshchenko, 1996)

As to **the East Bering Sea**, in the 1970s, the wintering pollock aggregations were observed on the upper continental slope westward off the Pribiloff

Islands and in Bristol Bay. Spawning aggregations were also registered on shelves of these regions (Fig. 2.6). With the water warming, pollock usually migrated from horizons of 150 – 400 m to middle and inner shelf waters for feeding during June – September (Maeda, 1972; Smith, 1981; Kinder, Schumacher, 1982; Francis, Bailey, 1983; Bakkala et al., 1985; Karp, Traynor, 1989). Feeding schools were formed at 58 – 61° N: resembling a broad band stretched in the north-west direction almost up to the south-east slope of Navarin canyon; in the inner Bristol Bay and eastward of the Zhemchug canyon (Fig. 2.6, 2.7, 2.8) (Maeda, 1972; Takahashi, Yamaguchi, 1972; Pereyra et al., 1976; Bakkala et al., 1985; Mito et al., 1990).

Like in the 1970s, at the turn of the century, the East Bering Sea shelf and upper continental slope accommodated at least three aggregations (the St.Matthew, Pribiloff, and Bristol ones) (Fig. 2.9).



W.G.: Wintering grounds; S.G.: Spawning grounds; F.G. : Feeding grounds

**Fig. 2.6.** Distribution of wintering, spawning and feeding concentrations of pollock (Maeda, 1972)

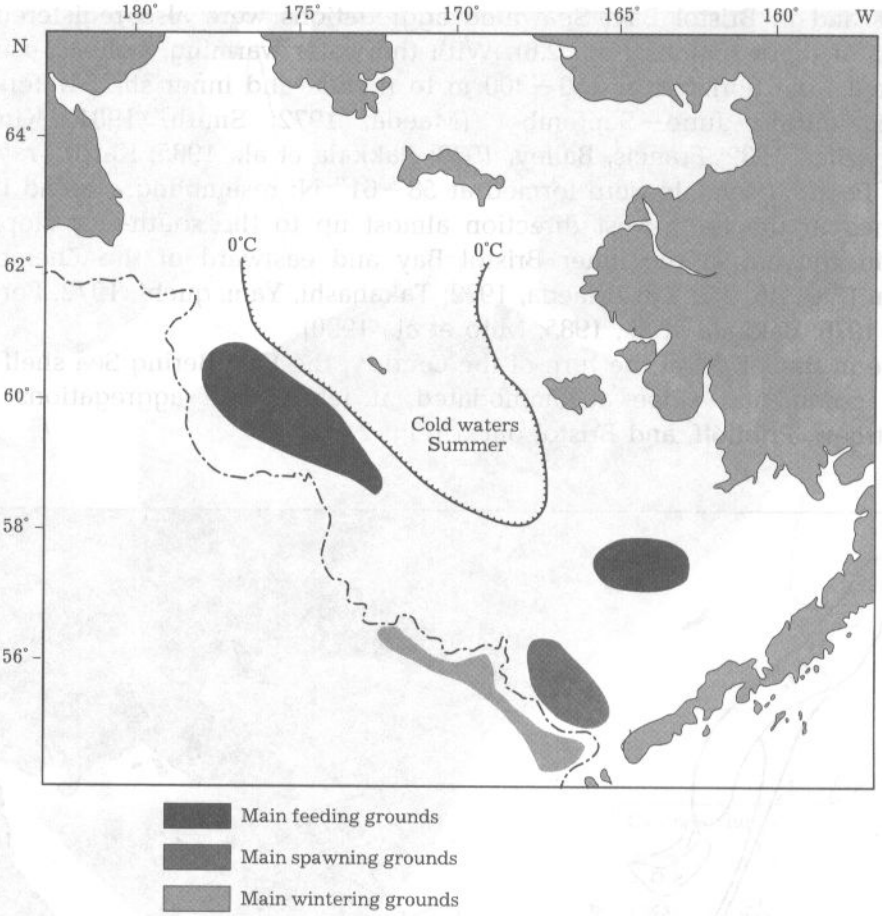


**Fig. 2.7.** Distribution of wintering, spawning and feeding concentrations of pollock in the 1970s (Mito et al., 1990)

In the 1970s, prewintering migrations **in Olyutor and Karagin Bays** started in late October. Pollock moved from the southern waters of Bays to the Lytke Strait and the continental slope. It was found that mature pollock wintered in the layer of up to 600 m in the area of the shelf break (300 – 1,050 m depth) off Karagin Island (Balykin, 1981; Kachina, Balykin, 1981). By the spawning period, the species usually migrated to waters over the inner part of the continental slope and further to shelf waters of Karagin and Olyutor Bays. The spawning took place at depths of 20 – 300 m (Kachina, Balykin, 1981) (Fig. 2.10).

At the end of spawning (June), the Olyutor-Karagin pollock, unlike its neighbors in the North and Northeast Bering Sea, moved to deep waters. Return migrations occurred approximately a month later and resulted in formation of feeding aggregations (July) in bays.

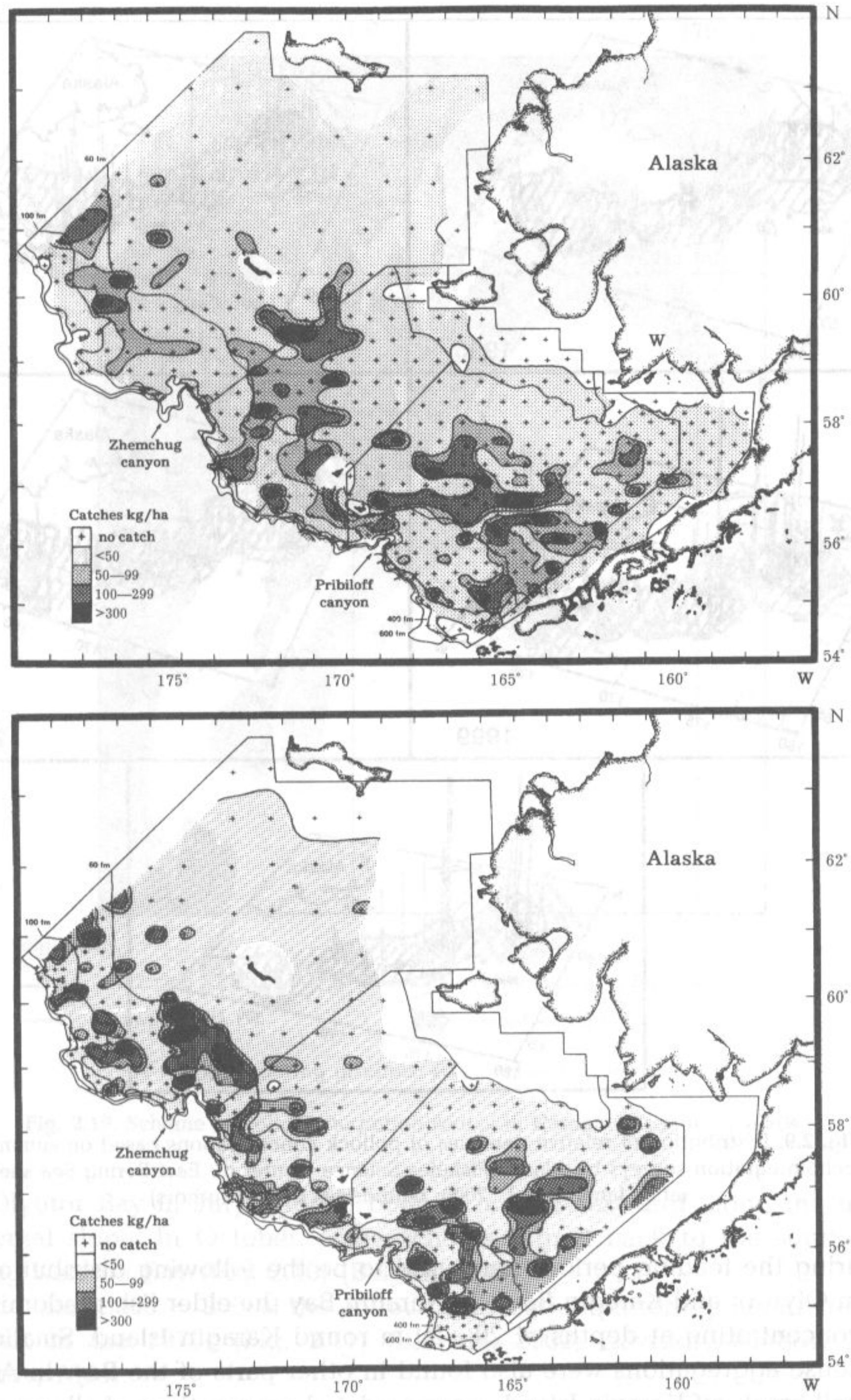


**Fig. 2.8.** Distribution and relative abundance of pollock, based on (*A*) U.S. and (*B*) Japanese bottom trawl survey in May—August 1979 (Bakkala et al., 1985)

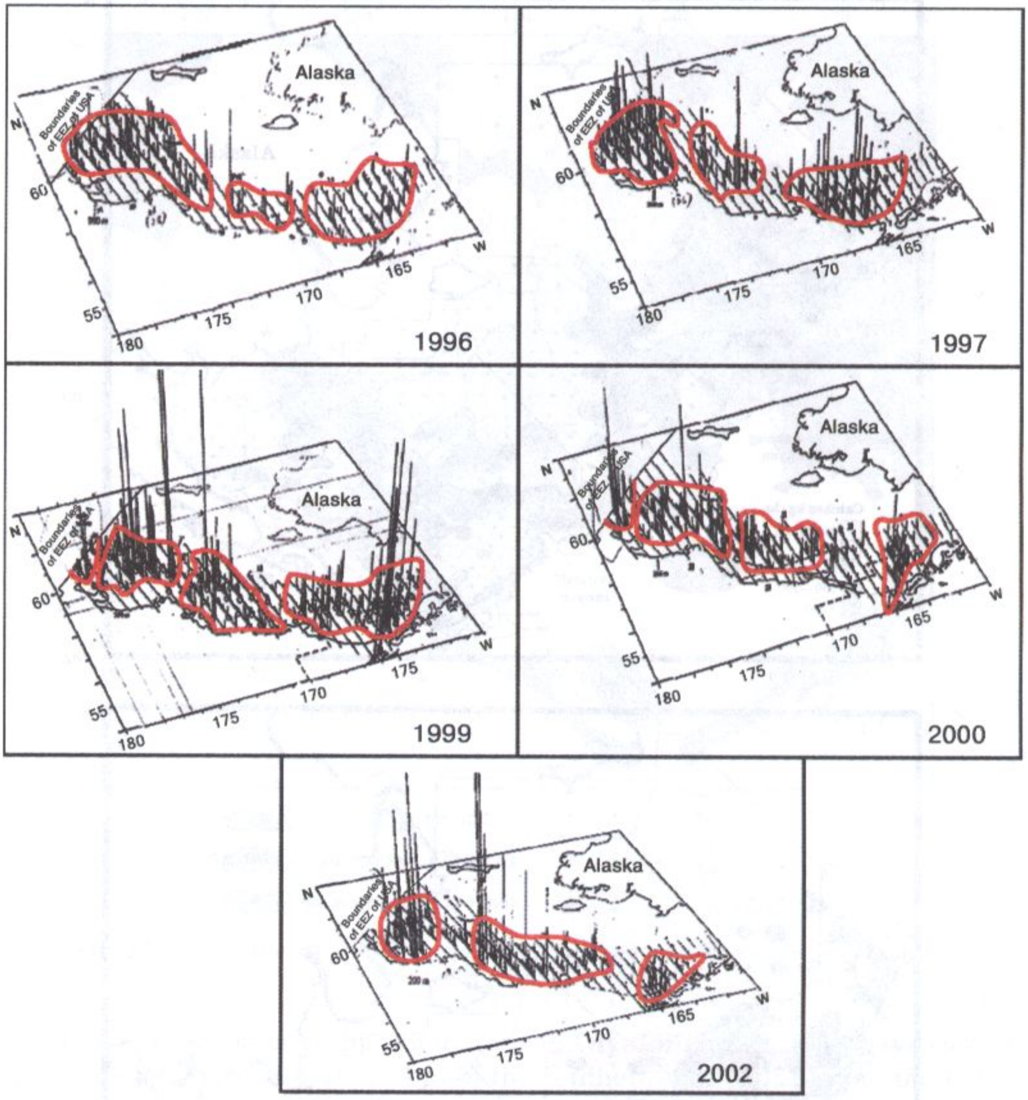


**Fig. 2.9.** Distribution of relative densities of pollock concentrations based on summer echointegration surveys by Alaska Fisheies Science Center on East Bering Sea shelf (after Ianelli et al., 2006; boundaries by the authors)

During the feeding period there used to be the following distribution pattern in Olyutor and Karagin Bays. In Karagin Bay the elder fish predominantly fed, concentrating at depths of 20 – 50 m round Karagin Island. Smaller and less dense aggregations were also found in other parts of the Bay. In August, the shelf break off Karagin Island accommodated aggregations of all age groups except the elder fish which had moved to the southern part of Karagin Bay.

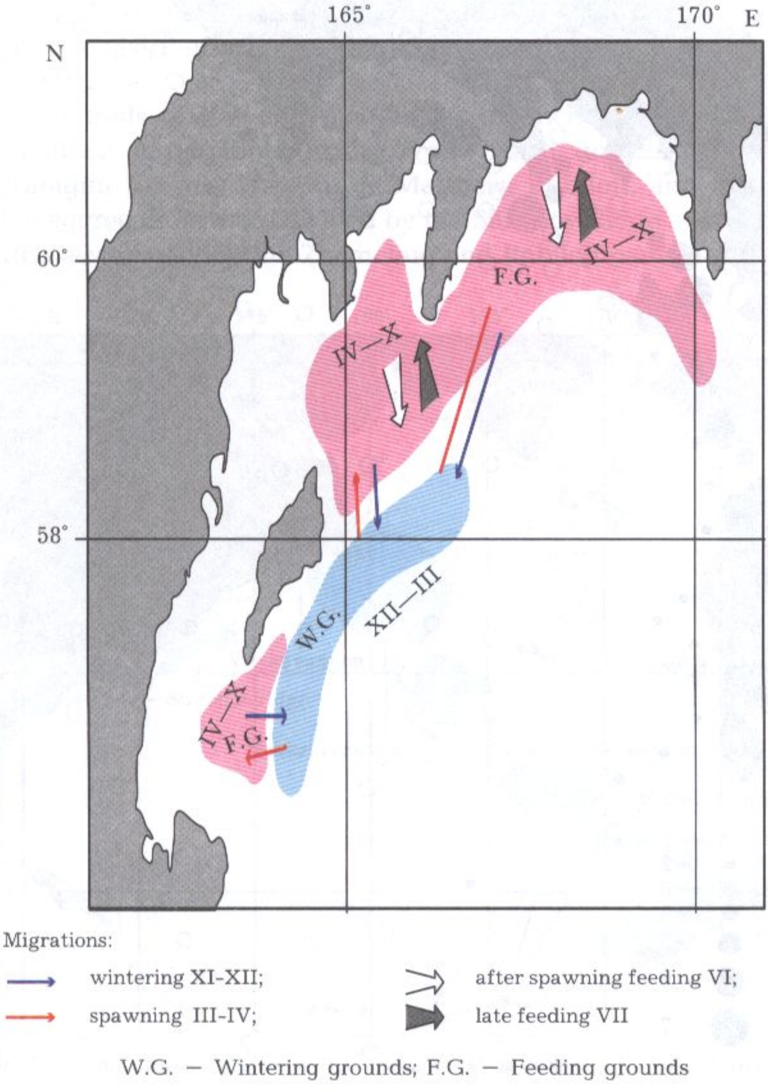
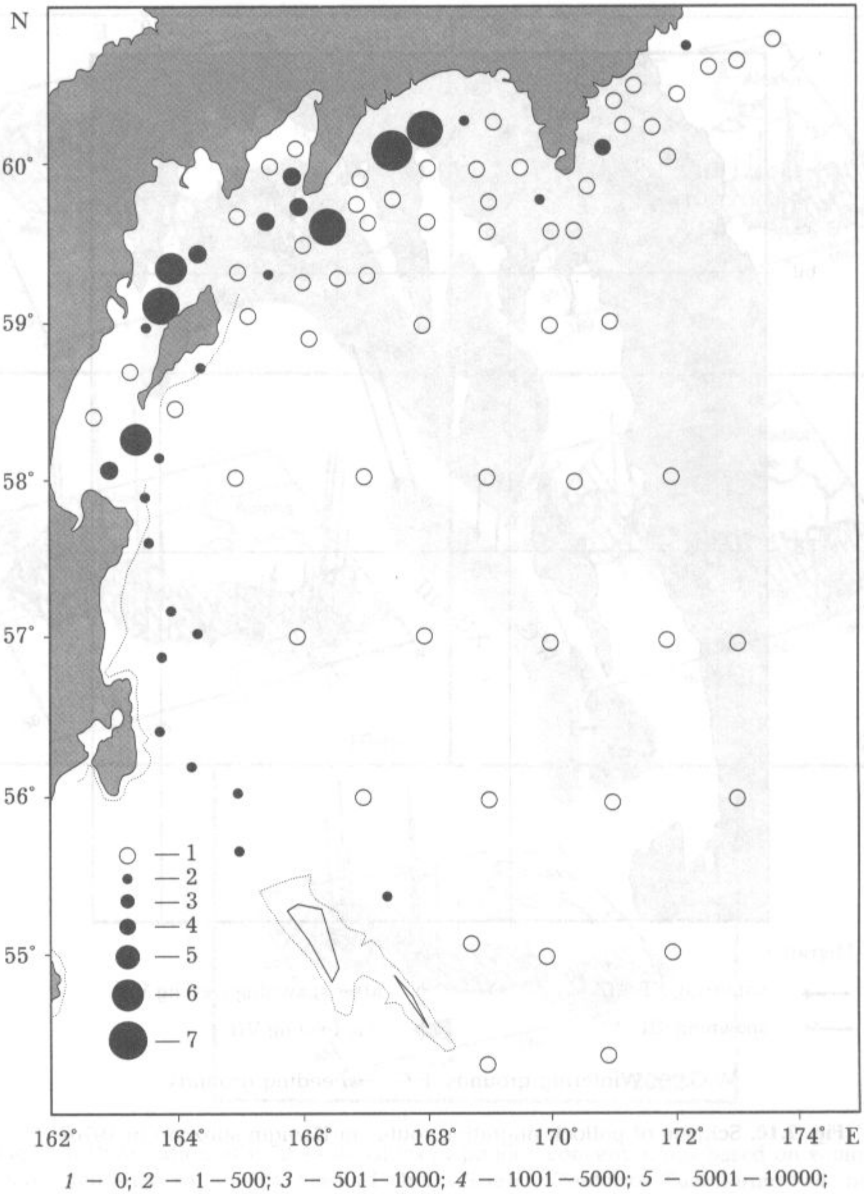


**Fig. 2.10.** Scheme of pollock migration routes in Karagin subzone in 1970s

In Olyutor Bay in July-August, pollock moved eastward along the upper continental slope. In October, some schools turned back to the south-west reaching Karagin Bay (Fig. 2.10) (Balykin, 1981).

In the late 1990s — 2000s, the pollock distribution pattern generally resembled that in the 1970s (Fig. 2.11) (Balykin, 2002; Gavrilov, Glebov, 2002; Glubokov, 2005).



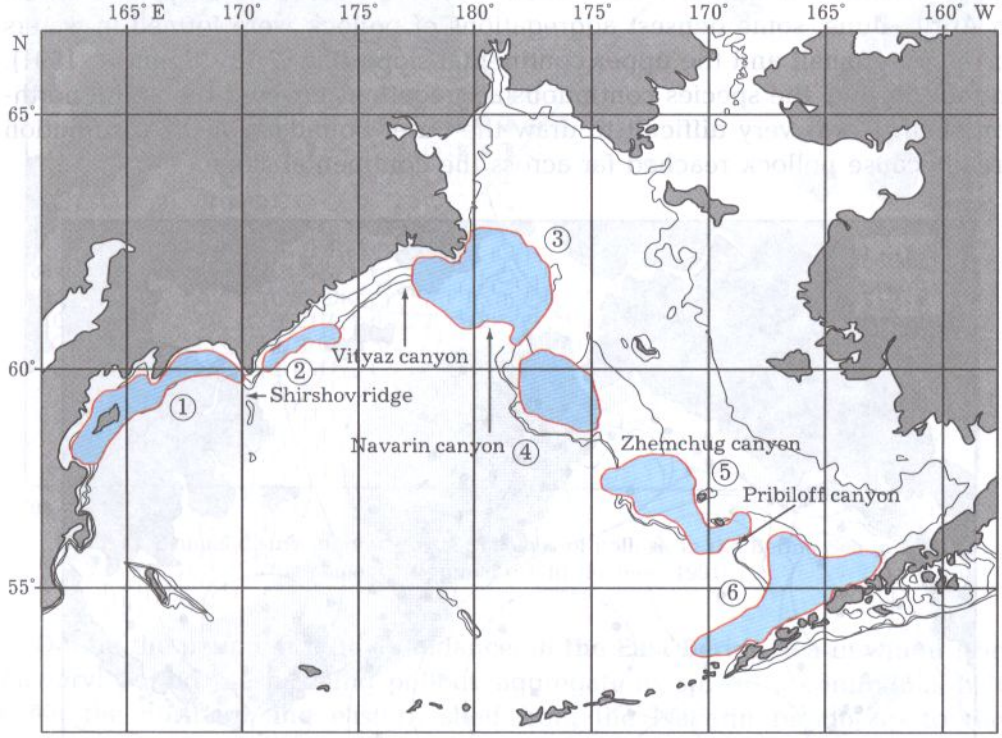
*1* – 0; *2* – 1–500; *3* – 501–1000; *4* – 1001–5000; *5* – 5001–10000;
*6* – 10000–100000; *7* – >100000

**Fig. 2.11.** Spatial distribution of pollock (ind/km$^2$) in West Bering Sea on September 26 – October 19, 2000 (Gavrilov, Glebov, 2002)

**In the Koryak region**, forming wintering concentrations, pollock migrated to the southwest at isobaths of 100–200 m (see Fig. 2.1, *c*). Wintering took place in waters over the continental slope, feeding resumed in shelf waters above depths of 50–140 m (see Fig. 2.1, *a*, *b*) (Balykin, 1981).

In periods of low and medium abundances, the southwest boundary of the Koryak pollock distribution was the Shirshov underwater Ridge (see Fig. 2.1) (Balykin, 1981).

Thus, in periods of low and medium abundances, there were six spatial secluded pollock aggregations in the West, North, and East Bering Sea: the Olyutor-Karagin, Koryak, Navarin, St.Matthew, Pribiloff, and Unimak-Bristol ones. These aggregations were divided by the Shirshov Ridge and the Vityaz, the Navarin (the eastern slope), the Zhemchug and Pribiloff canyones (Fig. 2.12).



Aggregations: ① - Olyutor-Karagin; ② - Koryak; ③ - Navarin; ④ - St. Matthew; ⑤ - Pribiloff; ⑥ - Unimak-Bristol.

**Fig. 2.12.** Scheme of spatial distribution of pollock in periods of low and medium abundance

## High abundance

The turn of the 1970s and the 1980s witnessed significant atmosphere and oceanologic shifts in the area of the Bering Sea, which affected the pollock distribution (Wyllie-Echeverria, Wooster, 1998). Changes in climatic/oceanologic conditions were identified by 40 indicators (Ebessmeyer et al, 1991; Niebauer, 1988; Beamish, 1993; Niebauer, Hollowed, 1993) and started in 1977. In 1983, another significant transformation of climate happened which was brought about by the strongest El-Niño in the 20th century (Hollowed, Wooster, 1992; Trenberth, Hurrel, 1994). The new regime caused increase in bioproductivity and appearance of several strong year-classes of pollock in warm years. Consequently, the Bering Sea pollock abundance increased sharply (Wespestad, Terry, 1984; Fadeev, 1990 a; Hollowed, Wooster, 1992; Wespestad, 1993; Shuntov et al., 1993; Shuntov, Dulepova, 1995; Shuntov et al., 1997; Ianelli et al., 2004).

In the 1980s in **the North Bering Sea** in winter period the Navarin pollock make intensive migrations from shelf waters to adjacent deepwater areas. In April–June, some densest aggregations of pollock were formed in waters of the outer shelf and the upper continental slope (Fig. 2.13) (Shuntov, 1991). In that decade, the species continuous aggregations covered the entire northern shelf. It was very difficult to draw the outer boundary of the distribution area because pollock reached far across the continental slope.

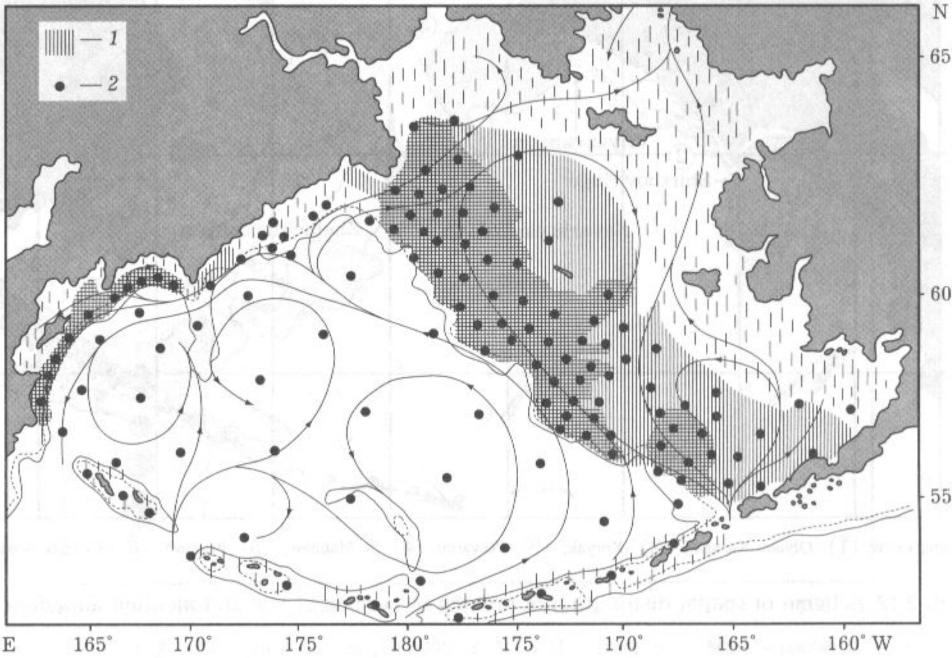


**Fig. 2.13.** Distribution of small size (under 30 cm) – (*1*) and medium size (30–40 cm) – (*2*) pollock in the Bering Sea in 1980s. Denser areas and spots reflect great concentrations (Shuntov, 1991)

Comparing pollock distribution in the winter-spring and summer-autumn periods, N.S.Fadeev came to the conclusion that firstly and secondly maturing fish, which participated in spawning on the Pribiloff-Unimak shelf, moved along the continental slope to the north after spawning (Fadeev, 1988, 1991).

Also on the Nortern Bering Sea shelf it was observed mixed feeding aggregations of pollock which spawned in the Navarin region and in the West Bering Sea (Balykin, Maksimenko, 1990; Fadeev, 1991). Uninterrupted distribution was confirmed by all surveys made in the 1980s, as well as by fishery data (Fig. 2.14) (Fadeev, 1991).

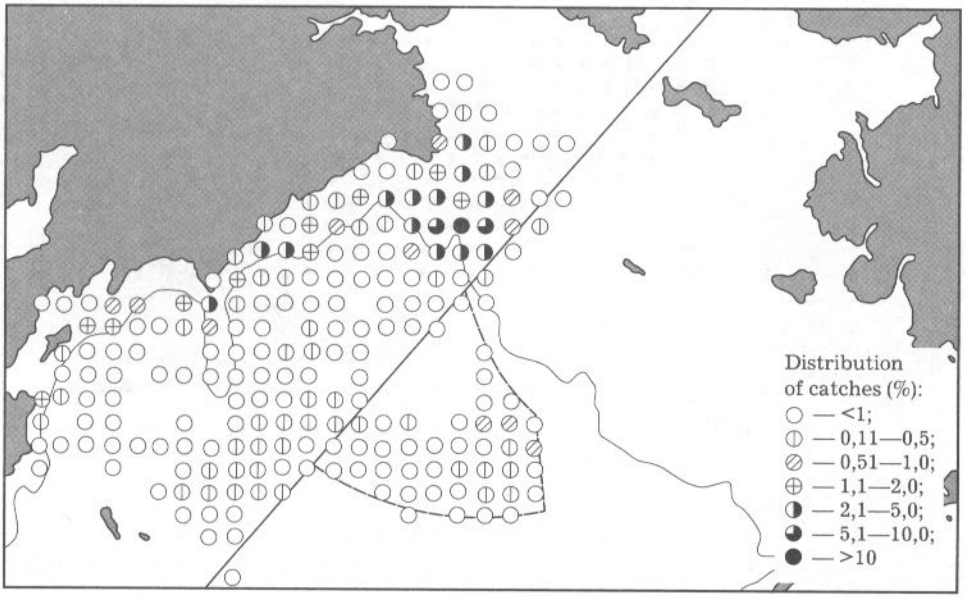


**Fig. 2.14.** Annual distribution of Russian catches of pollock in the Bering Sea in 1988 (percentage of annual catch) (Fadeev, 1991)

During the period of high abundance, in **the East Bering Sea** in winter (the January) period prespawning pollock aggregations spread a continuous belt along the northern and eastern shelf from the Navarin region up to the Aleutian Islands chine. In February – March, with the coming spawning season the Northeast Bering Sea pollock school divided into two aggregations: one – in waters off the Pribiloff Islands and the other – northward of the Zhemchug canyon (see Chapter 3). During feeding period (June–October) pollock aggregations within the US EEZ again covered almost the entire shelf and the upper slope (Megrey, 1989 a; Wyllie-Echeverria, 1995; Bailey et al., 1999 a). According to the US fishery data and surveys, the catch distribution confirmed continuity of the pollock distribution in the East Bering Sea, from the Aleutian Islands up to the border of the US EEZ (Fig. 2.15, 2.16) (Wyllie-Echeverria, 1995; Bailey et al., 1999 a).

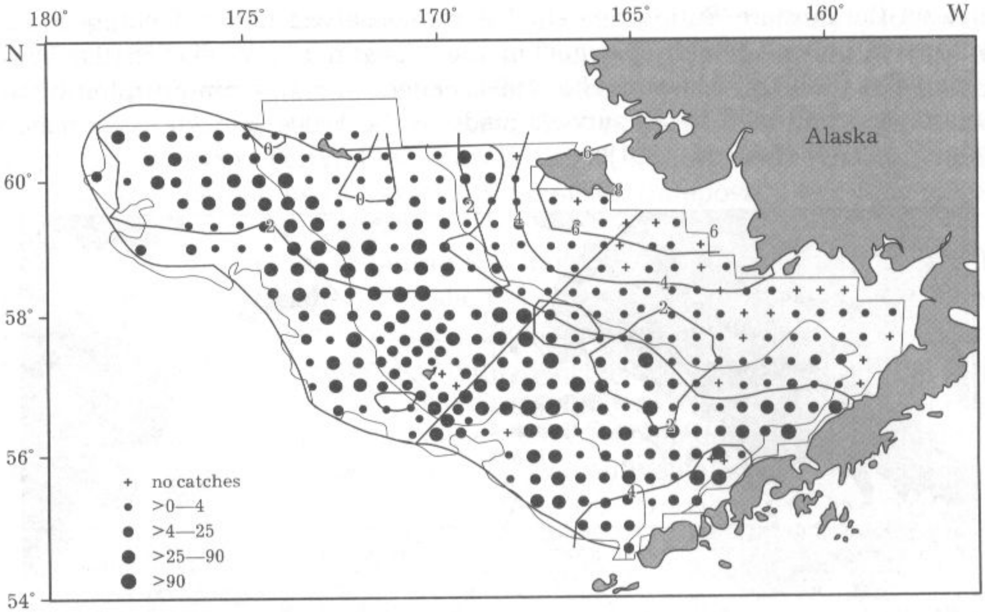


**Fig. 2.15.** Distribution of pollock catches per effort (kg/ha) in 1980 (Bailey et al., 1999 a)

In the 1980s, unlike the last decade, pollock migrated far beyond the continental slope (Wespestad, 1989); these aggregations provided for sustainable fishery in the Aleutian basin (Fig. 2.17). It was suggested that pollock migrated from the Northeast Bering Sea for feeding grounds in waters of the Koryak plateau to return in autumn (Radchenko, Sobolevskij, 1992).

**In the West Bering Sea**, during the period of high abundance in winter pollock formed aggregations at large depths and slowly shifted to the southwest occupying Olyutor, Karagin, and Ozernoy Bays (Balykin, Maksimenko, 1990; Balykin, 1996). Spawning pollock aggregations concentrated in the same areas, as well as in the area of the Koryak plateau opposite to Dezhnev Bight (Balykin, 1993).

Unlike in the 1970s, not all the pollock returned to the shelf after spawning in Olyutor and Karagin Bays; some schools spread for feeding to the deep-water area of the Kommandor basin, mainly migrating along the Shirshov underwater Ridge. It is clearly demonstrated by movements of the national fishing fleet (Fig. 2.17) (Sobolevskiy et al., 1989 a; Stepanenko, 1989; Fadeev, 1991; Glubokov, 2004 a).

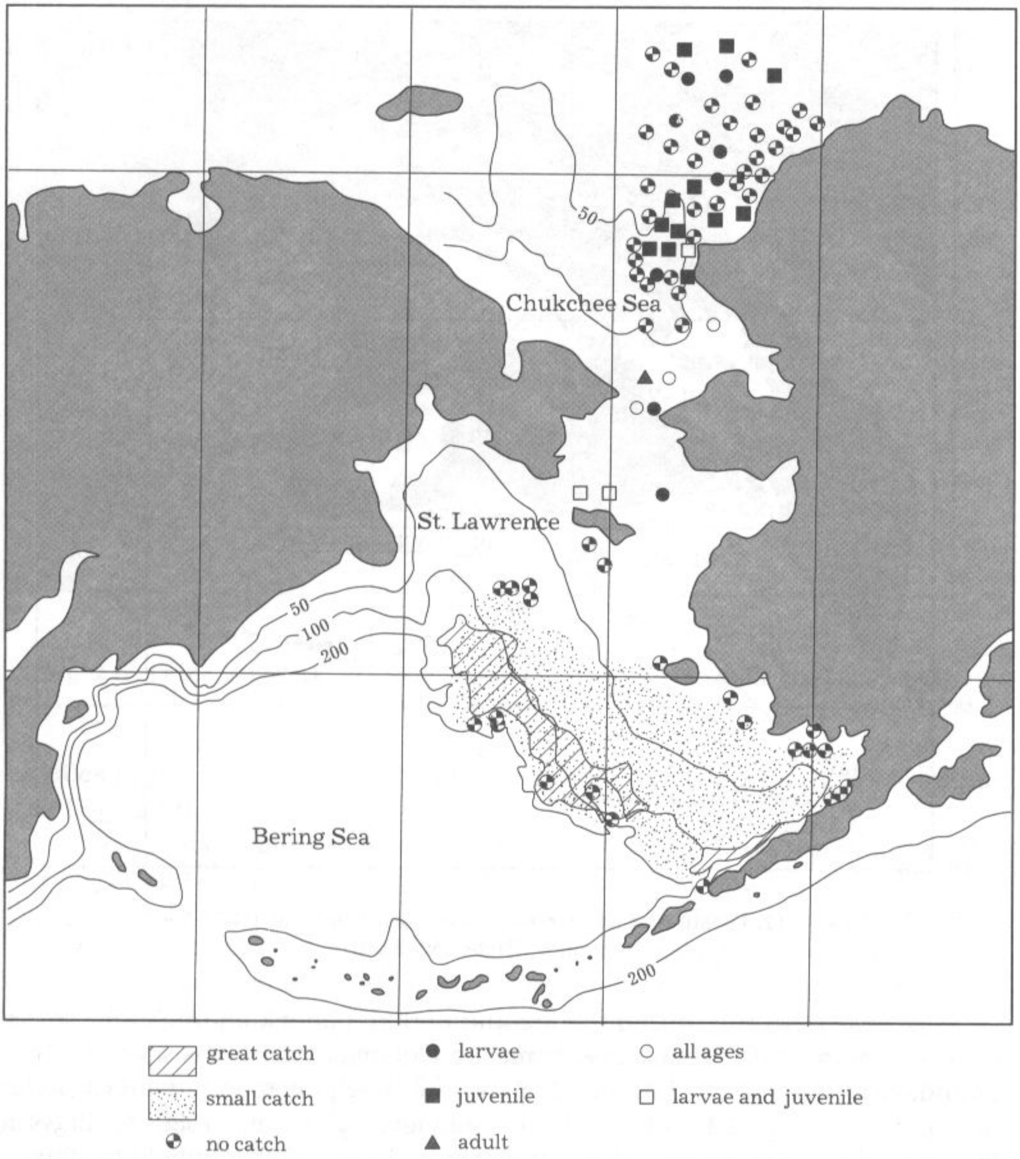


**Fig. 2.16.** Distribution of pollock of different ages based on surveys in July – September 1990 (Wyllie-Echeverria, 1995)

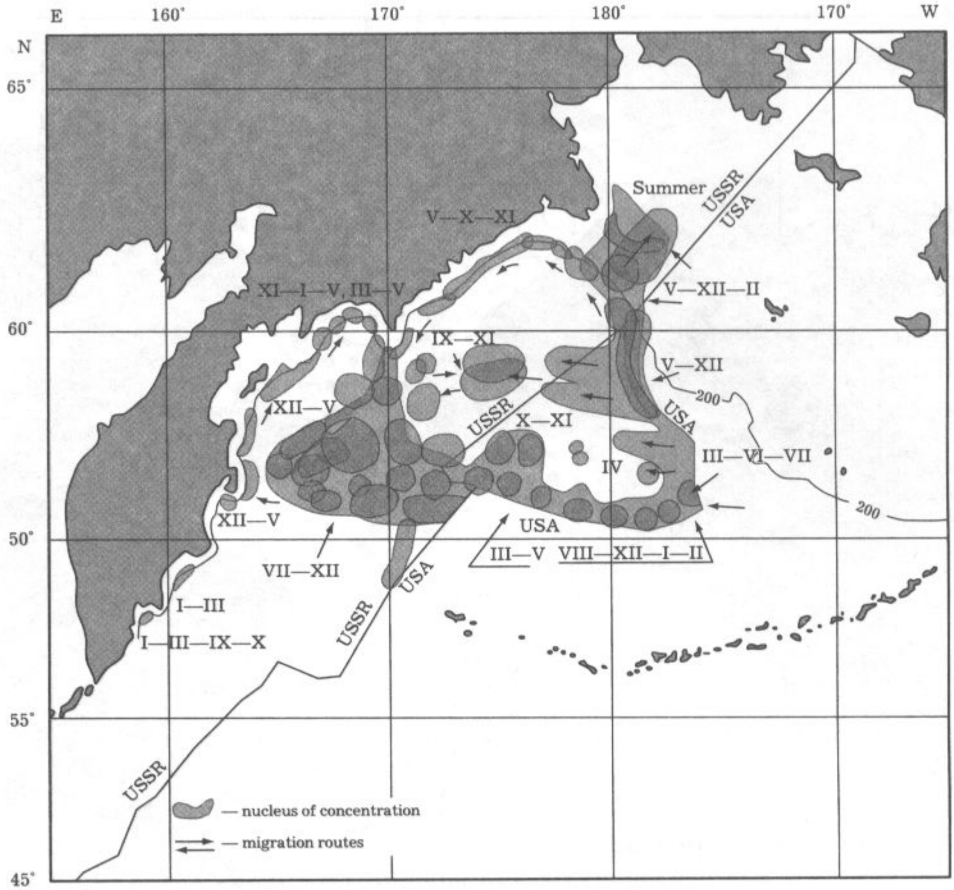


**Fig. 2.17.** Location of Russian fleet in pollock fishery in 1986 – 1990, by month (Glubokov, 2004)

After spawning and during the feeding period, pollock aggregations spread over the entire West Bering Sea, from the Kommandor Islands up to the east boundary of the Soviet EEZ (Fig. 2.18), where they joined with the East Bering Sea pollock (Fig. 2.13, 2.15 – 2.17) (Sobolevskiy et al., 1989 b; Balykin, Maksimenko, 1990; Fadeev, 1991; Radchenko et al., 1995; Glubokov, 2004).

Several scientists believe that there were migrations from the southwest to the northeast (Shuntov et al., 1993).

Echointegration trawl surveys made in the late 1970s – early 1980s revealed summer aggregations of pollock all over **the Aleutian basin** on horizons of 30 – 150 m (Fig. 2.19). Winter aggregations were found in the southeast waters over this basin (Okada, Yamaguchi, 1985; Okada, 1986). Concentrations in deepwater areas were so dense that fishing fleet of the USSR, Japan, Republic of Korea, China, and Poland could continue their

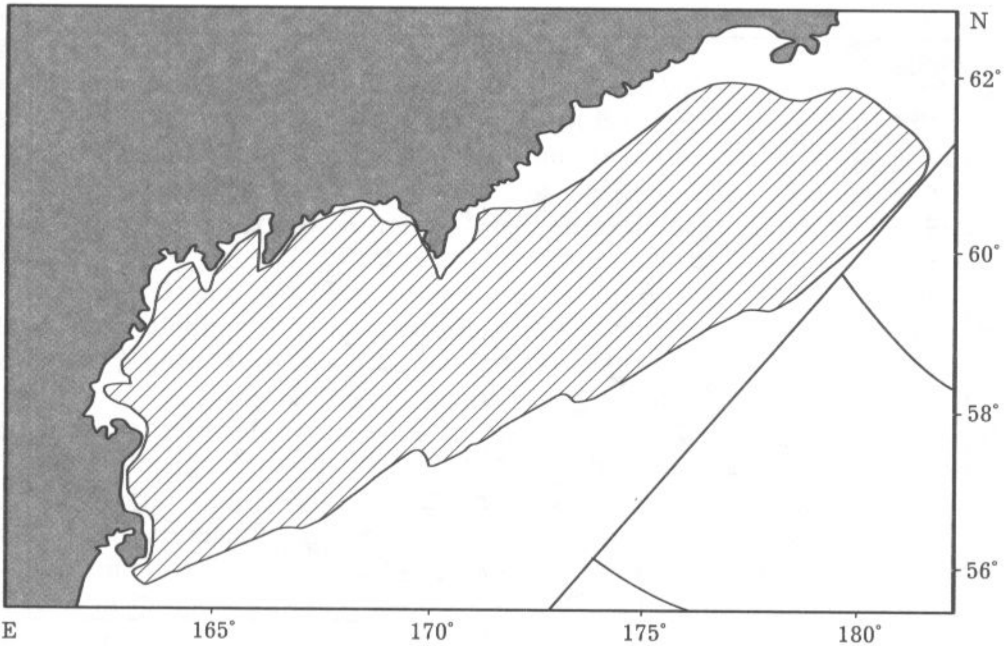


**Fig. 2.18.** Range of pollock concentrations in the West Bering Sea in June–July 1988 (after Fadeev, 1991)

activities in the Bering Sea basin all year round, following the pollock migrations (Fig. 2.17).

In those years, available data suggested that pollock could migrate to the Aleutian basin both from the East Bering Sea shelf and waters off the Aleutian Islands, and from the USSR fishery zone (Okada, 1986; Dawson, 1989 b; Fadeev, 1991; Shuntov et al., 1993). By the early 1990s, after depletion of the Bering Sea pollock abundance, the aggregations in the central basin disappeared (Borets et al., 2002; Glubokov, 2004 a; Glubokov, Popov, 2004 a,b).

The biomass growth of principal populations of the Bering Sea pollock which continued since 1977 till 1989 (Shuntov et al., 1993; Ianelli et al., 2004), resulted in a considerable increase in the species distribution area. Contemporary surveys in the Chukchi Sea revealed larvae, juveniles, and mature individuals of pollock (Fig. 2.16) (Wolotira et al., 1977; Wyllie-Echeverria, McRoy, 1992; Wyllie-Echeverria, 1995). Some pollock aggregations, which earlier remained within the shelf and on the upper continental slope, in great number left these waters in search of food for deepwater areas of the sea, while in the 1950s – 1970s these areas accommodated only scattered pollock schools (Dawson, 1989 b; Sasaki, 1989; Fadeev, 1991; Shuntov et al., 1993; Glubokov 2004 a). Previously isolated aggregations from the north, east, and west merged together. Migration routes grew longer and during

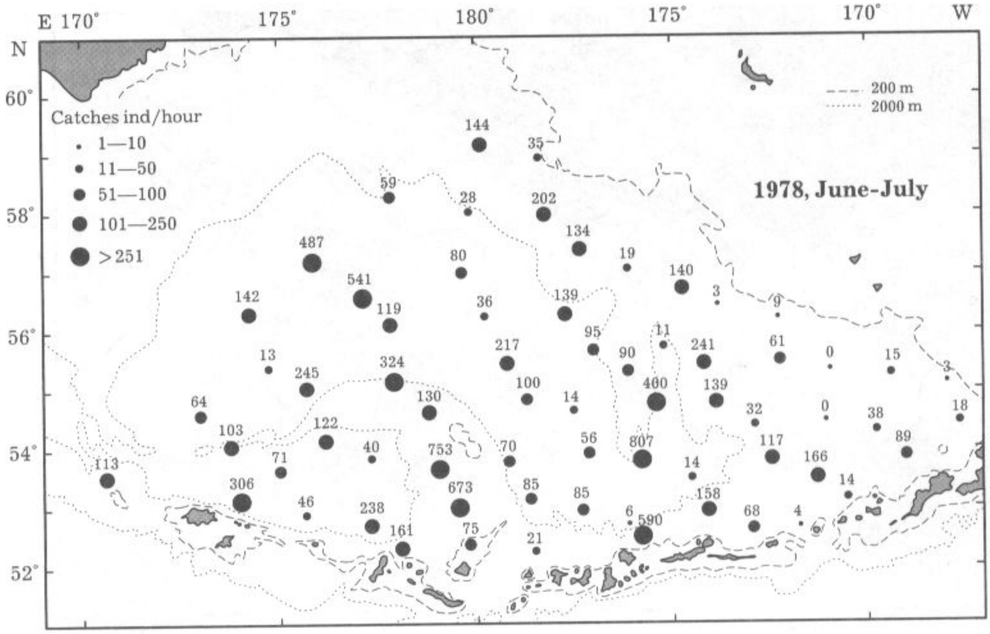


**Fig. 2.19.** Distribution of catches per unit effort of pollock in Central Bering Sea based on the results of Japanese trawl-echointegration survey (Okada, 1986)

the feeding period the Koryak shelf, the southern Navarin region, as well as the Aleutian and possibly the Kommandor basins became areas of formation of mixed aggregations. As a result, in the 1980s, the pollock life cycle was associated with almost the entire area of the Bering Sea (Radchenko, Sobolevskiy, 1992; Shuntov et al., 1993), both horizontally, and vertically. Striving for the maximum utilization of feeding, pollock made continuous shifts and daily vertical migrations, without forming any spatially or temporarily stable aggregations (Fadeyev, 1989 a).

Despite the fact that by the mid—1990s, general perceptions about spatial distribution of the Bering Sea pollock and its variations associated with the species abundance had been developed, there were still some considerable gaps in our knowledge which allowed for various interpretations of the pollock seasonal migrations. Such gaps emerged as a result that all long studies of the Bering Sea pollock spatial distribution and migrations (both national, and foreign) were assessed statically, i.e. on the basis of one-season surveys and not annual surveys. The obtained distribution pattern and migration data were supplemented by information on the fishing fleet displacements, which were obviously incomplete and sometimes biased.

Most controversial perceptions were connected with the North Bering Sea pollock aggregations. Some experts considered that the Navarin region was occupied principally by pollock originated from the East Bering Sea, which migrated here for feeding from the southeast waters to go back to its origin for spawning (Fadeev, 1991; Shuntov et al., 1993; Stepanenko, 2001 a). Another version stated that there was a North Bering Sea pollock population, which remained in the Navarin region during its entire life cycle and insignificantly mixed with the East Bering Sea aggregations (Serobaba, 1977; Kotenev, 1995; Glubokov, Kotenev, 1999; Datskij, 2000; Balykin, Varkentin, 2002 б).

Repeated during the year surveys are the only reliable technique of the direct determination of length and direction of the seasonal and ontogenetic migration routes. Since fundamental disagreements between hypotheses about formation of the North Bering Sea pollock aggregations concern the postspawning, feeding, and wintering periods, in 1996–2002, VNIRO, KamchatNIRO, and TINRO-center undertook joint annual surveys to study these three periods of annual cycles. This seven-year joint research program included 45 surveys made with periodicity of one week – six months.

According to the survey data on **the summer time**, which corresponds to the end of the postspawning period – the 1st half of the feeding period, the North Bering Sea pollock aggregations were formed on the upper continental slope and the outer shelf and their distribution pattern resembled a broad arc, which generally corresponded to the configuration of the outer shelf border. The top of the arc coincided with direction of the upper part of the Navarin canyon. The species distribution area virtually attained 175°30' E in the southwest; 62°30' N in the north; and 178–177° W in the east. In the Koryak region, pollock was especially abundant between 171° and 173° E (Fig. 2.20)

Repeated seasonal surveys (1996–2002) revealed the following interannual peculiarities of the Navarin pollock distribution in summer. In June-July, 1997, the densest aggregations belted Cape Navarin in the near bottom layer. In the area between 177° and 178° E, pollock aggregations were registered in 62°00'–61°40' N. Eastward of 180°, the species concentrated further to the south, in 61°40'–61°20' N. The principal part of the Navarin pollock schools were located in the area between 180 and 178° W and 61°20' и 62°30' N. Further to the southeast of the line connecting coordinates 62$^0$30' N, 177°00' W and 61°00' N, 178°30' W, there were no pollock aggregations (Fig. 2.21, *a*) (Glubokov, 2003). The year 1997 could be considered moderately warm. Due to the earlier warming of waters and the zooplankton development, pollock started its feeding migration from the upper continental slope to the area of the quasistationary eddy eastward of Cape Navarin already in June – early July. During the correspondent period in the cold 1999 (marked by slow processes of the ice cover retreat and water warming in early summer) (Stepanenko, Nikolaev, 2004), the Navarin pollock stayed in its wintering grounds along the shelf edge at depths of 250–350 m and did not spread further to the north of Cape Navarin (Fig. 2.21, *d*). The year of 2000 was also cold and as a result, in June, pollock kept to the southern waters of the Navarin region, in a narrow belt along 61° N at the slope boundary (Fig. 2.21, *g*). According to data of the bottom trawl survey made in the cold 2001, the main nucleus of aggregation was also stretched in the northwest direction from 178°00 W, 61°00 N to 180°00 62°00 N signifying the onset of feeding migration. However, due to the slow water warming and, consequently, late development of zooplankton in shallow waters, in June 2001, pollock delayed its migration to principal feeding grounds which were located on the central shelf to the north of 62° N (Fig. 2.21, *i*).

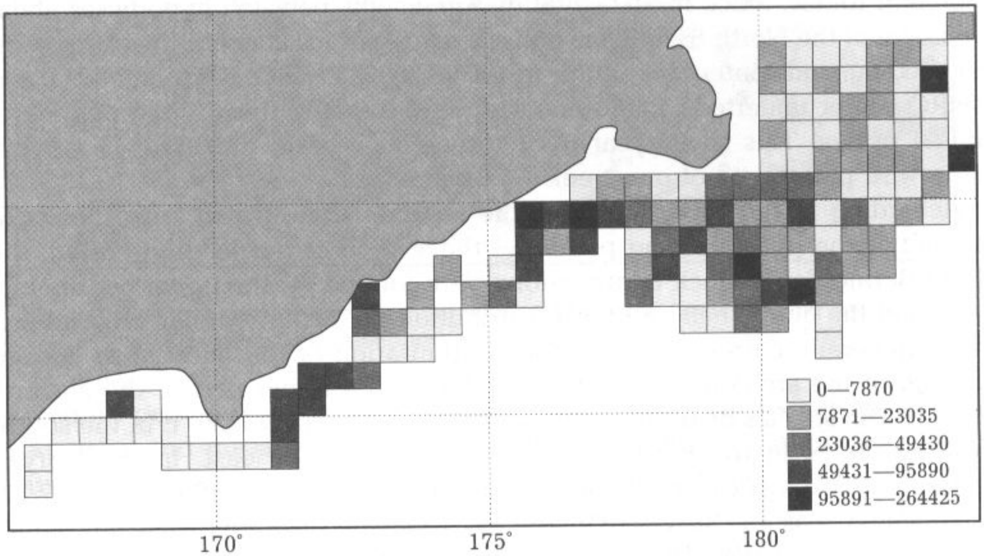
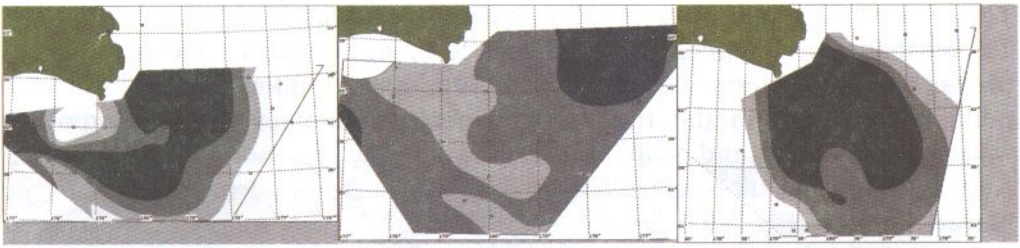


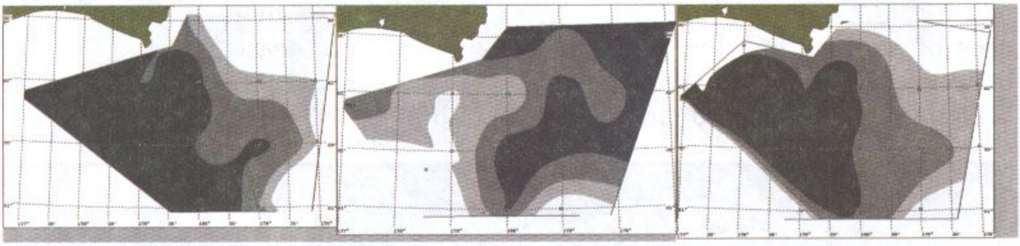
**Fig. 2.20.** Distribution density of near-bottom pollock (kg/mile$^2$) based on multiannual data from summer trawl surveys in 1996 – 2003

Therefore, during the postspawning period pollock generally kept to the outer shelf and the slope. As a rule, the concentration nucleus was completely aggregated (Glubokov, 2003).

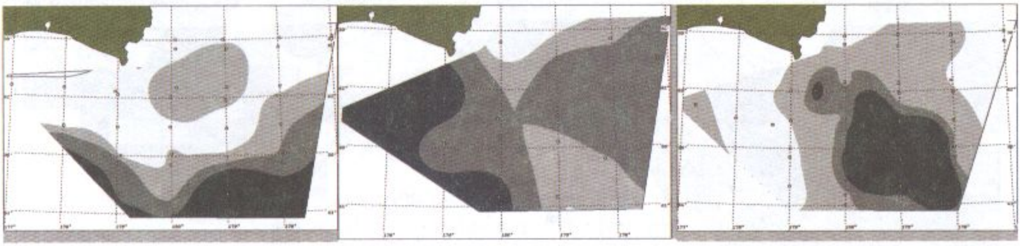
During the feeding period, the species began to move to shallow waters of Anadyr Gulf where the echosounder registered dense concentrations of zooplankton. In September, 1997, large schools of pollock were found in the bottom layer (at depths of <150 m) northward of 62° N, between 178°30' and 176°00' W (Fig. 2.21, *b*). In August of the cold 1999, the Navarin pollock did not finished its feeding migrations from the outer shelf though the largest part of the bottom concentrations had already moved northward of Cape Navarin (Fig. 2.21, *e*). In August, 2001, there were two nucleuses of feeding aggregations in the Navarin region: the first on the regular site of shelf (176°00 W, 62°30 N), and the other on the outer shelf to the west of 180° (Fig. 2.21, *j*).



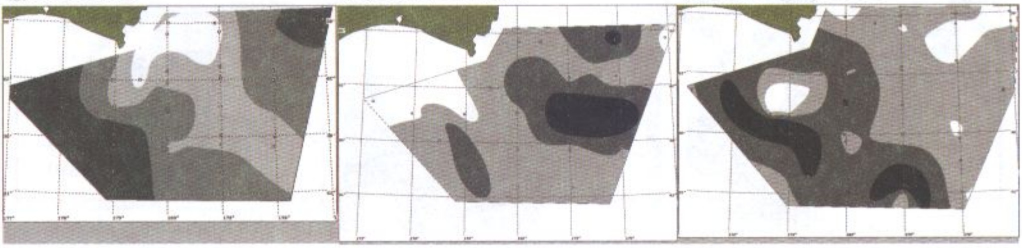
(a) June-July 1997 (b) September 1997 (c) November 1998



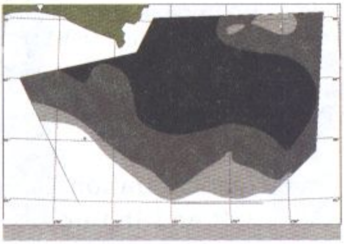
(d) June 1999 (e) August 1999 (f) December 1999



(g) June 2000 (h) October 2000 (i) June-July 2001



(j) August 2001 (k) October-November 2001 (l) August-September 2002



(m) November 2002

**Fig. 2.21.** Spatial distribution of pollock in Navarin area of the Bering Sea based on bottom trawl surveys (darker field = greater density of concentrations)

The year of 2002 was very cold. According to survey made aboard the R/V *TINRO* in June – July, cold water masses formed off St.Lawrence Island occupied entire the Navarin region. The isotherm of +2 °C was an obstacle to the pollock spreading in the region (Stepanenko, Nikolaev, 2004). A gradual warming of waters and shift of the cold spot to the north only began in August. After that the species could successfully migrate into the shelf of the Navarin region (Fig. 2.21, *l*).

**In autumn** (the 2nd half of the feeding period – early prewintering period), in the Navarin region in late 1990s – early 2000s there were two nucleuses of aggregation: the first was found to the northeast of Cape Navarin between 179 and 176° W, and the second was located to the south of Cape Navarin between 179°30′ and 177° E at depths of 180 – 310 m (Fig. 2.22).

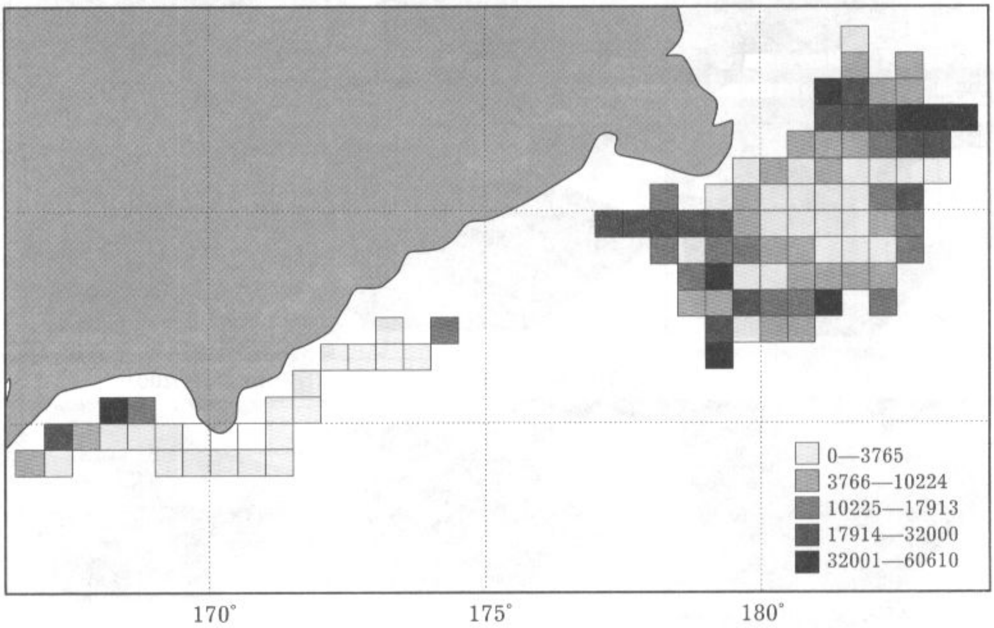
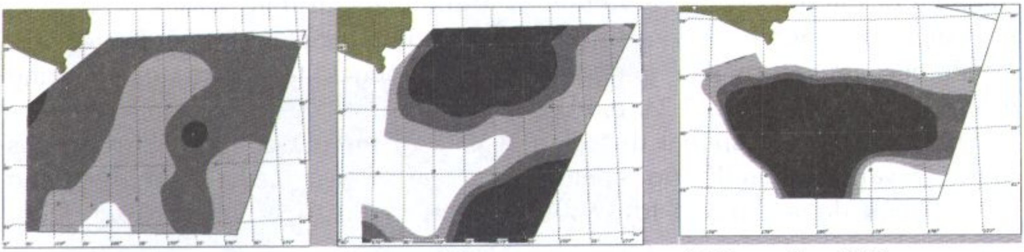


**Fig. 2.22.** Distribution density of near-bottom pollock (kg/mile$^2$) based on multiannual data from autumn trawl surveys in 1996 – 2003

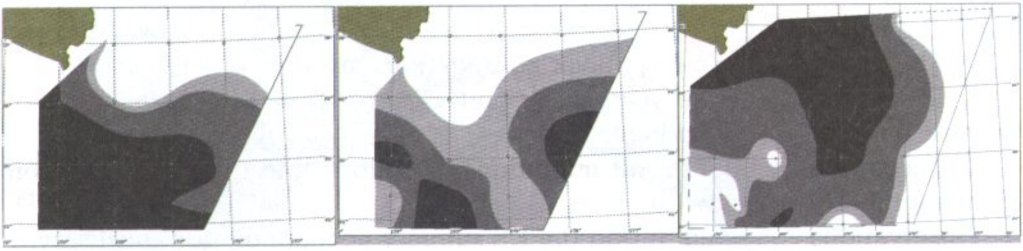
Wintering migrations in October – November reached the outer shelf and further across the slope (Fig. 2.21, *c, h, k*).

**In winter** (December), main concentrations of the Navarin pollock were located in waters of the outer shelf and the upper continental slope. No pollock was found in shallow waters of the region in winter (Fig. 2.21, *f*). By the end of the year pollock concentrated in the same waters as in April – May, i.e. the species finished formed their wintering aggregations in December.

With the objective to follow ontogenetic migrations of the Navarin pollock, we used data of numerous surveys to plot maps of the spatial distribution of two year classes of pollock, 1999 and 2000, for four years of sequential seasonal observations (Fig. 2.23, 2.24).



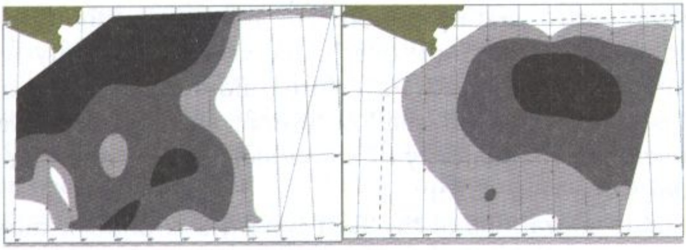
(a) December 1999 (b) June 2000 (c) November 2000



(d) June-July 2001 (e) August 2001 (f) August-September 2002

**Fig. 2.23.** Spatial distribution of the 1999 year-class of pollock in Navarin area in 1999 – 2002. Darker area shows greater density of concentrations

(a) November 2000 (b) June-July 2001 (c) August 2001



(d) August-September 2002 (e) November 2002

**Fig. 2.24.** Spatial distribution of the 2000 year-class of pollock in Navarin area in 2000 – 2002. Darker area shows greater density of concentrations

In the figure it could see fairly well that at the onset of the feeding period (June–July) immature pollock, including all age classes, from 1 year class till three-year-old fish, concentrated in the mature fish wintering grounds (Fig. 2.23, *b, d*; 2.24, *b*). In July–September, the main bulk of juveniles fattened in the area of the quasistationary eddy off Cape Navarin (Fig. 2.23, *e, f*; 2. 24, *c, d*), which sustained high concentrations of feeding zooplankton. In November-December, immature fish joined the adult pollock to return to wintering grounds (Fig. 2.23, *a, c*; 2.24, *a, e*).

Summarizing the spatial distribution pattern for the pollock aggregations in the Navarin region during repeated in a year surveys made when the Bering Sea pollock demonstrated low abundance, it could draw the following conclusions.

1. The Navarin pollock did not made long migrations and generally did not leave the boundaries of the North Bering Sea shelf and the continental slope.
2. The North Bering Sea pollock aggregations are very secluded.
3. In all periods of the year cycle, pollock formed mixed aggregations of recruits and mature individuals.
4. There were no significant migrations of pollock into the Navarin region from southeast or southwest.

Observations collected during the US summer echointegration trawl survey (2004), in which one of the authors participated, show that the southeast boundary of the Navarin pollock aggregations runs somewhere to the west of 176° W and to the north of 61° N. In cold years (e.g. 2002), pollock reached out far into American waters in summer months (Stepanenko, Nikolaev, 2004). In warm years (e.g. 2004), only insignificant part of Navarin pollock aggregations remained in American waters in summer months (Fig. 2.4).

Taking the above said into consideration, the mean long-term pattern of distribution and migrations for the Navarin pollock at the turn of the century could be presented as follows. In November-June, the species stayed over the continental shelf and slope. Later, in June-July, pollock migrated for feeding to the northeast with the Navarin current, along the Navarin canyon. The larger number of individuals stayed for feeding at depths of 80–100 m on the mid-shelf for the entire feeding period. The minority, without forming highly dense aggregations, spread all over Anadyr Gulf in July-August. Since September, the species started its return migrations. First, in September-October, pollock left the Gulf shallow waters which cooled early. Later, in October–November, the majority of individuals left the shelf for wintering on the continental slope (Fig. 2.25).

Theories about migrations of the East Bering Sea pollock into the Navarin region could never explain: why in some years, the species only comes to the Navarin region for feeding in October; at what age and in which month pollock returns from the Navarin region to the southern waters?

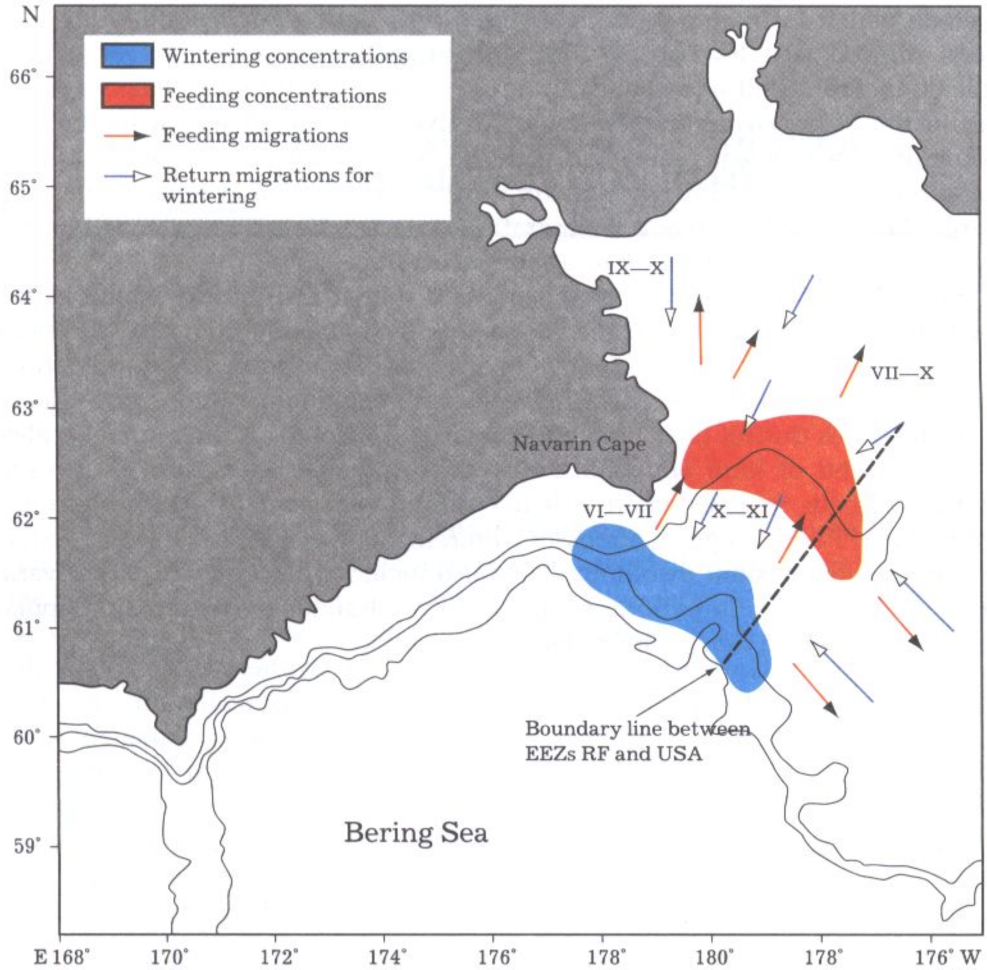


**Fig. 2.25.** Scheme of migration routes of navarin pollock
(late 20-th and early 21-st centuries)

Conducted analysis made possible to state that in fact those were local migrations in the area of delimitation of marine jurisdictions of Russia and the US, and they depended on time of the water warming in the Navarin region.

It is also unclear, at what age the elder pollock returns to the Navarin region again to settle in the bottom layer for the rest of its life?

Our data on seasonal distribution of the North and East Bering Sea pollock as well as publications about its distribution in summer and autumn prove that nowadays there are no mass migrations of adult pollock from the southeast to the northwest waters.

Thus, observations made during repeated in a year seasonal surveys made possible to obtain an unambiguous answer to the question about the origin of pollock which form aggregations in the North Bering Sea. Monthly observations showed that for seven years (1996–2002), the major part of pollock stocks, including all age classes, from 0+ year class till elder fish, was staying in the Navarin region. The majority always remained within the biotope boundaries, which was associated with the Navarin current and adjacent quasistationary eddies (Glubokov, 2005). Further evidence of absence of the East Bering Sea pollock ontogenetic migrations into the Navarin region will be discussed in Chapter 4 on the size-at-age structure.

Summing up the analysis of the pollock spatial distribution in the North, East and West Bering Sea for the entire period of studies (more than 70 years), it is possible to conclude the following. The species forms stable aggregations within particular biotopes. Most individuals in such aggregations never leave these biotopes during their life cycle on either seasonal, or interannual scales. During period of high abundance migration intensity increases. As a result pollock spreads to areas where it is only found occasionally in periods of low abundance. Pollock aggregations of different genesis mix together in waters of the species constant dwelling. Chapter 6 includes a scheme of the Navarin pollock distribution in period of high and low abundances with main populations of the Bering Sea pollock (Fig. 6.5).

# CHAPTER 3

## SPAWNING OF THE BERING SEA POLLOCK AND ITS MATURATION RATE

The essential point in identification of marine fish populations which have not clearly defined distribution area is their association with particular spawning grounds (Ogawa, 1956; Hinckley, 1987; Glubokov, Kotenev, 1999). In the previous chapter it was shown that the North Bering Sea accommodated stable pollock aggregations both seasonally and interannually, as well ontogenetically. Identification of genesis of the northern pollock aggregations, however, demands knowledge about their reproduction in the North Bering Sea and adjacent waters.

### Reproduction. Spatial differentiation of the main spawning grounds

It is well-known that species which eggs and larvae develop in the pelagic layer, including pollock, spawn in areas with a circular system of currents where eggs and larvae are safe from drifting out to waters with unfavorable conditions (Moiseev 1952, 1953 a, б, 1963; Kaganovskaya, 1960; Kashkina, 1965; Haldorson, 1989). Concentrations of the Bering Sea pollock eggs vary significantly with geographical areas and yearly conditions (Incze et al., 1984; Bulatov, 2004).

**In the North Bering Sea,** ichthyoplankton studies were made occasionally (Musienko, 1963, 1970). Besides, till the mid-1970s, surveys had mostly started on the eastern shelf and then moved to the northwest. As a result, ichthyoplankton surveys in the Navarin region were only performed in the summer-autumn period, when the main spawning peak had been already passed (Gorbunova, 1954; Musienko, 1963). This caused underestimation of the egg number. For the first time pollock eggs were found in Anadyr Gulf in the early 1930s (Shmit, 1933). The second published finding of individual eggs in Olyutor and Anadyr Gulfs was made in August—September, 1950 (Gorbunova, 1954). Maximum numbers of pollock eggs in the 1930s – 1984 were registered in the southwest waters of Anadyr Gulf (105 ind/m$^2$) in June 1952 (Table 3.1, Musienko, 1970).

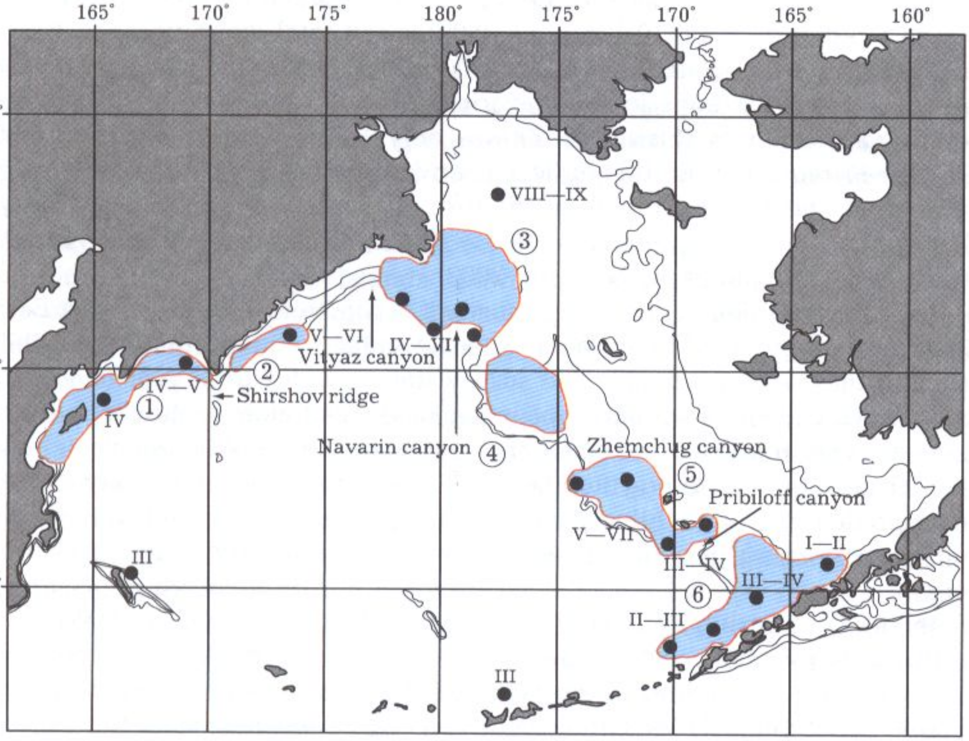
**Table 3.1.** Maximum number of developing pollock eggs in the Northwest Bering Sea, spring-summer, ind/m$^2$

| Year | Olyutor-Karagin region | | Western Koryak shelf | | Navarin region | | Source |
|---|---|---|---|---|---|---|---|
| | Period | Egg number | Period | Egg number | Period | Egg number | |
| 1952 | June | 528 | – | – | June | 105 | Musienko, 1970 |
| 1965 | – | – | – | – | May | 50 | Serobaba, 1968 |
| 1971 | – | – | 6–8 June | 176 | – | – | Balykin, Varkentin, 2002 б |
| 1971–1972 | – | – | early June | 50 | early June | 50 | Kachina, Balykin, 1981 |
| 1972 | June | 76 | 4–11 June | 28 | 11–16 June | 24 | Balykin, Varkentin, 2002 б |
| 1984 | – | – | 2–4 June | 28 | – | – | Balykin, Varkentin, 2002 б |
| 1984 | – | – | 4–12 June | 48 | – | – | Balykin, Varkentin, 2002 б |
| 1985 | 25 April – 22 May | 1816 | 25 April – 22 May | 1902 | 25 April – 22 May | 116 | Bulatov, Kuleshova, 1994; Balykin, Varkentin, 2002 б |
| 1985 | – | – | mid June | 334 | mid June | 74 | Balykin, Varkentin, 2002 б |
| 1986 | – | – | 5–9 May | 1460 | May | 424 | Balykin, Varkentin, 2002 б |
| 1993 | – | – | mid May | 668 | – | – | Balykin, Varkentin, 2002 б |
| 2000–2001 | 08–28 April | 10 | 08–28 April | 52 | 14 April – 13 May | 38 | Glubokov, Norvillo, 2002 |

*Note:* «–» – no data available.

After establishment of the 200-mile zones and termination of the Soviet pollock fishery on the East Bering Sea shelf, interest in the northwestern pollock aggregations has increased considerably. Several spring-summer expeditions were organized and there were also publications of data on ichthyoplankton collections performed in previous decades (Kachina, Balykin, 1981; Bulatov, Kuleshova, 1994). Results of these studies confirmed interannual stability of the North Bering Sea spawning grounds (Moiseev, 1983; Borets et al., 2002; Bulatov, 2004, Glubokov, 2005). For this period of studies, the maximum density of the pollock egg concentrations in this area was registered in May 1986 (424 ind/m$^2$) (Balykin, Varkentin, 2002 b).

Figure 3.1 illustrates spatial differentiation of the pollock spawning grounds in the Bering Sea. In the northern waters, the pollock spawning grounds encircle the Navarin canyon. The westernmost spawning ground in the Navarin region is located on the boundary of the shelf and continental slope, eastward off the Vityaz canyon. The northernmost one is in the central part of Anadyr Gulf.



● — main spawning grounds; Roman numbers – monthes of intensive spawning; other notations in 2.12.

**Fig. 3.1.** Spatial differentiation of the main spawning grounds of pollock in the Bering Sea (after Stepanenko, 2003; Bulatov, 2004; Glubokov, 2005)

Time of spawning varies considerably with climate and oceanological peculiarities in a particular year, this is especially true about the northern pollock populations. In the 1950s – 1970s, the maximum numbers of eggs were collected in the Navarin region in May – June; in the succeeding decades, maximum collections occurred in April – May (Table 3.1). In late June – July, fish that enter the grounds in spring-summer finishes its spawning (Glubokov, Norvillo, 2002; Datskij, 2004 a). In August – September, Anadyr Gulf becomes a place of breeding of a relatively small number of large-sized pollock individuals (Gorbunova, 1954; Datskij, 2002).

Calculated by averaged data on the recorded number of eggs for the period of 1984–1989, portion of eggs from the North Bering Sea (Navarin) spawning grounds made 8.7 % of the total number of eggs from spawning grounds in Russian waters of the Bering Sea (Fadeev, 1991). In 1984–1987, the total number of eggs in the Olyutor-Navarin region was 6.3 times less than in the Pribiloff waters, and 2.1 times less than in the Korfo-Karagin region (Bulatov, 1989). The year 1988 witnessed the maximum recorded number of eggs in the Navarin region – $13{,}1 \cdot 10^{11}$ ind., i.e. 8.0% of the total egg number in Russian EEZ (Gritsai, Stepanenko, 2003). In 2000–2002, according our own data the number of pollock eggs in the Navarin region (35.9–38.7% of the recorded total egg number in Russian EEZ) was only 1.6–1.8 times less than in the Olyutor-Karagin region; this indicated an increasing importance of spawning grounds in the Navarin region at the turn of the century, and, respectively, a decreasing relative importance of those in the West Bering Sea (Olyutor and Karagin Bays) (Glubokov, Norvillo, 2002).

As it was mentioned above, egg surveys in the North and Northwest Bering Sea are not regular, while in the northeast waters (to the north off the Pribiloff Islands) they are occasional. The survey timing varies from year to year and not always coincides with the spawning peak. Therefore, abundance estimations are very relative and allow only for determination of tendencies to interannual variations. The egg number could be more or less precisely assessed on the data of several ichthyoplankton surveys made in an extensive area during one spawning period, similar to those concerning the Okhotsk Sea pollock.

**In the East Bering Sea**, one of the first ichthyoplankton surveys was made in the spring-summer of 1965 and covered the area from Unimak Island up to Cape Navarin. According to the obtained data, the maximum density of eggs totaled 3,463 ind/m$^2$ (Serobaba, 1968). According japanese data the egg concentrations of great density were registerred in two areas of the eastern shelf: to the northwest and southeast off the Pribiloff Islands (Maeda, 1971; Maeda, Hirakawa, 1977). Spawning pollock concentrations were also found in catches in those waters (Traynor, 1986). Based on the pollock distribution in spawning period, E.I.Moiseev (1983) also concluded that there were two large spawning grounds on the eastern shelf, i.e.: in the Unimak region (to the southeast off the Pribiloff Islands) and in the Pribiloff region (to the northwest of the islands). The third spawning ground of a smaller size was found in the northeast part of the sea, off St.Matthew Island (Moiseev, 1983). Several scientists confirmed presence of pollock eggs in the St.Matthew region in the 1960s – 1980s (Maeda, Hirakawa, 1977; Bulatov, 1987; Fadeev, 1991; Shuntov et al., 1993). Since the early 1990s to the present day, however, no pollock spawning has been registered in this region. This could be associated with actual cessation of spawning in years of low and medium abundance of populations, as well as with lack of information resulted from absence of ichthyoplankton surveys in the Northeast Bering Sea since 1991.

By the early 1990s, identification of the East Bering Sea pollock spawning grounds was almost completed. The Pribiloff and the Unimak-Bristol spawning grounds were recognized as the most productive (Maeda, 1971; Serobaba, 1974 b; Maeda, Hirakawa, 1977; Traynor, 1986; Bulatov 1987; Hinkley, 1987; Dawson, 1989 a; Stepanenko, 1989; Shuntov et al., 1993; Bulatov, 2004; Swartzman et al., 2002). The Pribiloff region includes four well-defined nucleuses of spawning, two of them are located to the south of the Zhemchug canyon and the other two – along the northern edge of the Pribiloff canyon. In the Unimak-Bristol spawning ground the majority of the spawning shoals concentrates off Bogoslof Island and Unimak Island and in the southwest part of Bristol Bay (Fig. 3.1).

In the Unimak-Bristol region the species breed in January – April, in waters southward off the Pribiloff Islands spawning takes place in March – April, while off the southern part of the Zhemchug canyon it occurs in May – July (Serobaba, 1968; Maeda, 1971; Maeda, Hirakawa, 1977; Traynor, 1986; Stepanenko, 2003).

In the 2nd half of the 1980s, eggs from the Pribiloff region made 23.1% of the total recorded number for the Bering Sea in the US exclusive economic zone (Fadeev, 1991). The maximum number of the East Bering Sea pollock eggs in all years of observations was registered in 1990 and totaled $3{,}699.1 \cdot 10^{11}$ ind. In the late 1980s – early 1990s, the most intensive spawning took place on the shelf off the Pribilof Islands where the egg number totaled $398.2 \cdot 10^{11}$eggs (1985), $1{,}678.5 \cdot 10^{11}$ eggs (1988), $566.3 \cdot 10^{11}$ eggs (1989), $2{,}102.6 \cdot 10^{11}$ eggs (1990), and $583.6 \cdot 10^{11}$ eggs (1992), or 53.6 – 69.0% of the total recorded number of the East Bering Sea pollock eggs (Gritsai, Stepanenko, 2003). In warm years, relative significance of the Unimak-Bristol spawning ground increased in comparison with the Pribiloff one (Brodeur et al., 1998).

According to Japanese scientists, there could be a mixing of spawning aggregations of the East Bering Sea pollock (Nishiyama, Haryu, 1981), which degree depended on the population abundance. Other researchers (Hinckley, 1987, Bulatov, 2004) believe that there were no mixing of any pollock aggregations in the spawning period, *inter alia* due to their different spawning periods. We presume that in years of low abundance spawning aggregations of the East Bering Sea pollock population are completely isolated, while in years of high abundance there could be some mixing. An unambiguous answer about panmixia of either the East Bering Sea pollock aggregations, as for the northern schools could be only found through annual repeated ichthyoplankton surveys. It is difficult to provide an adequate assessment of the East Bering Sea pollock population structure without such data.

**In the West Bering Sea**, the first discovery of pollock eggs was made eastward off Karagin Island and near Cape Olyutorski in June 1932 (Shmit, 1933). During the ichthyoplankton survey aboard the R/V *Vityaz* (May-June, 1952), maximum numbers of eggs (264) were taken in waters off the northeastern coast of Karagin Island (Musienko, 1970). In the 1960s, the pollock egg density was low and did not exceed 50 eggs/m$^2$ (Serobaba, 1968). In the 1970s according data of ichthyoplankton surveys in 1971, 1975, 1978, and 1979, the average density of eggs totaled 0.2−0.7 ths/м$^2$ with the maximum values below 1,000/м$^2$ (1,5−7,9) (Kachina, Balykin, 1981). Unfortunately, data on absolute numbers of catched pollock eggs in Olyutor and Karagin Bays in the 1980s and 1990s were not published.

Pollock spawning in the Northwest Bering Sea occur in shelf waters or on the shelf break of Karagin and Olyutor Bays. Principal nucleuses of spawning activity are located between Cape Golenishchev (Karagin Island) and Goven Peninsula in Olyutor Bay (Fig. 3.1). Location of spawning grounds in the West Bering Sea is relatively permanent on the interannual scale (Borets et al., 2002).

It was suggested that in the 1970s, pollock breeding in the West Bering Sea occurred in April-July (Kachina, Balykin, 1981). Recent data has revealed that prespawning pollock could also be found in Olyutor and Karagin Bays in August (Balykin, Maksimenko, 1990; Glubokov, 2005). Early ichthyoplankton studies by Gorbunova (1954) confirmed that there could be an autumnal small peak of spawning in Olyutor Bay.

On the interannual scale, time of the pollock spawning in the West Bering Sea (like in other areas) depends on water enthalpy (Balykin, 1997). Spawning usually starts eastward of Karagin Island in late April, then mass spawning spreads into Olyutor Bay to continue till mid-May (Kachina, Balykin, 1981; Bulatov, 1986; Zilanov et al., 1989; Balykin, 1993; Shuntov et al., 1993).

In the 1980s characterized by persistent ice cover, spawning was delayed and started May 5−20 attaining its maximum intensity May 10−15 (Balykin, 1993).

During the last decade, the majority of pollock spawned April 20 − May 5 with the peak in the last decade of April. Judging by examinations of spawning shoals in Olyutor Bay in the 2002 with low ice covering, the spawning peak was attained at the beginning of the 2$^{nd}$ decade of April and virtually finished by April 24 (Glubokov, 2005). In 2007, Olyutor and Karagin Bays also had the least ice cover in the last four years (Fig. 3.2). The spring survey in 2007 aboard the F/V *Vasiliy Kalenov* showed that in the Karagin subzone of the East-Kamchatka zone the largest number of pollock females with gonads at the IV−V and V stages of maturity occurred April 25.

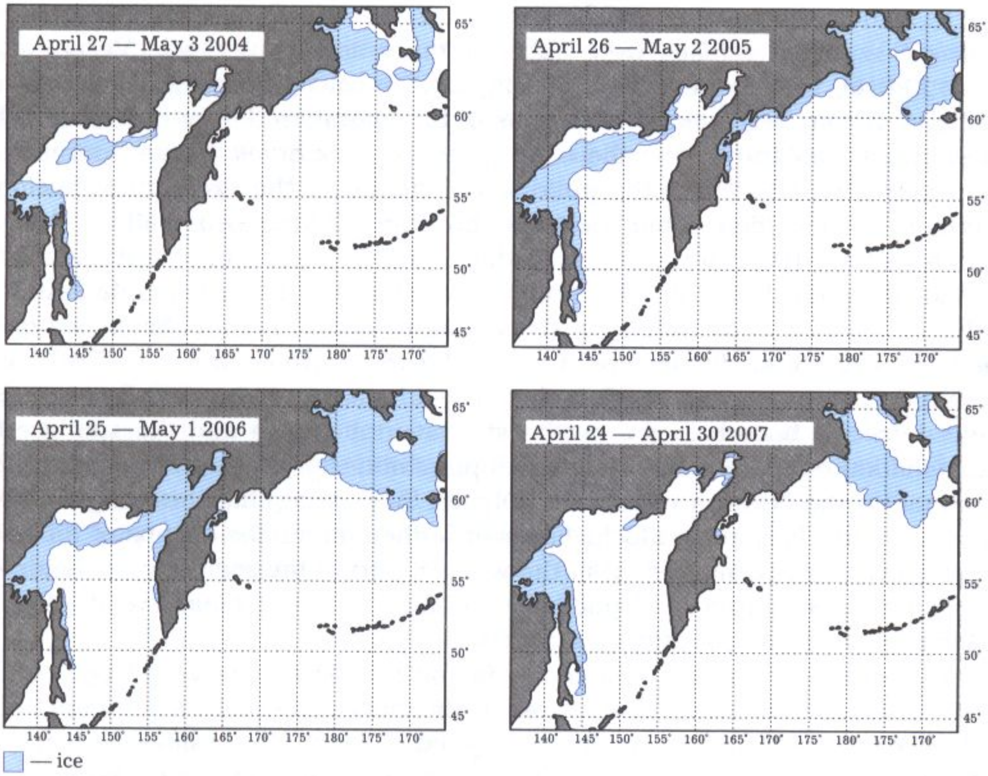


**Fig. 3.2.** Distribution of ice cover in Northwest Pacific (data from Laboratory of Sattelite Monitoring Fishing Regions (VNIRO))

In 1984–1989, the portion of pollock eggs in Ozernoy Inlet and Karagin Bay made 18.9% of the total recorded number of eggs in Russian waters of the Bering Sea, while in Olyutor Bay it was 51.5% (Fadeev, 1991). E.V.Gritsai and M.A.Stepanenko reported that the portion of recorded pollock eggs westward of 170°30 E, in Olyutor and Karagin Bays was 53.3% in 1985 and approximated 85.3% in 1992. In 1985–1992, the averaged portion of pollock eggs in the western part of the sea made 4.7% of the total number of eggs in the Bering Sea with the maximum of 7.7% in 1992 (Gritsai, Stepanenko, 2003). In the 1980s, according May ichthyoplankton surveys in this region, the recorded number of pollock eggs varied in the range of $2 \cdot 10^{12} - 20 \cdot 10^{12}$ eggs (Balykin, 1993). According O.A.Bulatov (1985) data this number totaled $6{,}936 \cdot 10^{12}$ eggs in 1984.

There is no significant influx of pollock eggs to the West Bering Sea from other spawning grounds (Balykin, Varkentin, 2002 б). It is noteworthy that ratio of the recorded eggs in the western and eastern parts of the sea and ratio of catch levels in these regions are very different. Thus, in 1988, the egg number in waters westward of 170°30 E was 11.2 times lower than in the East Bering Sea, while catches were only 3.1 times smaller (Fadeev, Vespestad, 2001; Gritsai, Stepanenko, 2003). Using similar calculations for the Navarin and East Bering Sea pollock, adherents of the migration theory conclude that the northern waters receive the east transport of embryos, larvae, and juveniles which together with the pollock production of the northern spawning grounds provide high catch levels in the North Bering Sea (Fadeev, 1991; Shuntov et al., 1993). If we accepted this logics in case of the West and East Bering Sea pollock, we should recognize existence of a considerable eastern influx of pollock eggs (≈72%) to the Olyutor-Karagin region. Another argument in favor of such assumption could be the current direction. The East Bering Sea slope current reaches the Koryak coast at 175–176° E, where it splits into two branches: the northeast (Navarin) stream and the southwest (Kamchatka) one. Then, there are equal possibilities of the southeast transport of larvae to the Navarin region and Olyutor Bay. Accepting these arguments in case of the Navarin pollock, however, adherents of the theory of distant migrations always claimed that in the western part of the sea there are neither migrations, nor transport of pollock eggs from the east (Sobolevskiy et al., 1991; Fadeev, 1991; Shuntov et al., 1993).

The reason for such discrepancies in the numbers of recorded eggs and catch levels is very likely to be a relatively small-scale pollock reproduction in the West and North Bering Sea; this could account for considerable underestimations of eggs and larvae in the course of single ichthyoplankton surveys, which, due to climatic and oceanologic peculiarities of a particular year as well as subjective reasons (time of financial support, research permits, etc.) could miss the spawning peak or be made in areas without concentrations of pollock eggs in a particular year. On the contrary, the large-scale pollock reproduction in the East Bering Sea and in the Sea of Okhotsk off West Kamchatka as well as repeated surveys decrease the estimation dependence on time and region of surveys, because high concentrations of eggs persist all over large areas for a long time.

Differences in ratio between abundance of pollock at its early stages of ontogenesis and that of mature fish in the East and Northwest Bering Sea could be associated with higher rates of survival of embryos and larvae in favorable climatic, hydrological, and biological conditions provided *inter alia* by the Northwest Bering Sea quasistationary eddies.

Another spawning ground was registered **in the Koryak waters**. There are no regular ichthyoplankton surveys conducted during intensive spawning in this part of the sea, nevertheless, we could cite several publications on the Koryak pollock reproduction. First data on number of developing eggs are dated early June 1971 (Balykin, Varkentin, 2002 б). Then the maximum catch of eggs totaled 88 (176 eggs/m$^2$). Like in the Navarin spawning grounds, maximum egg catches in the Koryak waters were taken in the 1980s. In May 1985, density of pollock eggs off the Koryak coast attained 1,902 eggs/m$^2$ (Bulatov, Kuleshova, 1994). By early June, the density dropped down to 334 eggs/m$^2$. In 1986, the catches was comparable with the previous year: 1,460 eggs/m$^2$ (Balykin, Varkentin, 2002 b). The succeeding decade witnessed decrease in pollock abundance, and as result in number of recorded eggs. Thus, in mid-May 1993, the egg density in the Koryak waters totaled 668 eggs/m$^2$ (Balykin, Varkentin, 2002 b).

The main nucleus of the pollock spawning was located in the southwest Koryak region (Fig. 3.1). According to surveys made by VNIRO, KamchatNIRO, and TINRO-center in 1996–2002, during periods of low and medium abundance, there was no spawning of the Koryak pollock in some years.

In years of high abundance, intensive spawning characterized the western and central Koryak region, between 171° and 173° E and between 174° and 176° E (Balykin, Varkentin, 2002 б).

The peak of spawning occurred in May - early June. In 1998, the maximum abundance of mating males was registered in the waters limited by 172°40'–173°20' E and 60°40'–60°50' N in May 8 (Bizikov, personal communication).

In the 1980s, winter catches taken **in the Bering Sea enclave** contained spawning pollock (Hinkley, 1987; Mulligan et al., 1989). In 1994–2006, after decrease in abundance of principal pollock stocks in the Bering Sea, however, there were no captures of either spawning fish, or pollock eggs at all.

During the entire period of studies, pollock **larvae** were abundant in waters of the North, East, and West Bering Sea. Thus, Japanese larval surveys (June-August) showed that in 1963–1974, pollock larvae were widely distributed in the North and East Bering Sea, from 64° N in Anadyr Gulf up to 54° N in Bristol Bay and the Aleutian Islands (Fig. 3.3) (Maeda, Hirakawa, 1977; Haryu, 1980). But for all that T. Haryu suggested that the larval distribution coincided with location of spawning grounds of the North and East Bering Sea pollock (Haryu, 1980). Russian regular ichthyoplankton surveys (1971–1988) also showed presence of pollock larvae in the East Bering Sea, Navarin region, Koryak waters, and Karagin subzone in May–July (Fig. 3.4, 3.5) (Fadeev, 1991; Balykin, Varkentin, 2002 б). Figure 3.4 demonstrates clearly that larval concentrations in the northern waters of Anadyr Gulf coincide with the local eddy (Fig. 1.6).

Summarizing all the discussed in this section made it possible highlight the following. Some of the identified in chapter 2 pollock aggregations have stable spawning grounds both spatially and temporarily. Such aggregations include: the Olyutor–Karagin one (2 spawning grounds), the Navarin aggregation (5 spawning grounds), the Pribiloff one (4 spawning grounds), and the Unimak-Bristol one (4 spawning grounds). According Maeda, Hirakawa (1977) and Sasaki (1989) pollock larvae captured in the Bering Sea enclave in the

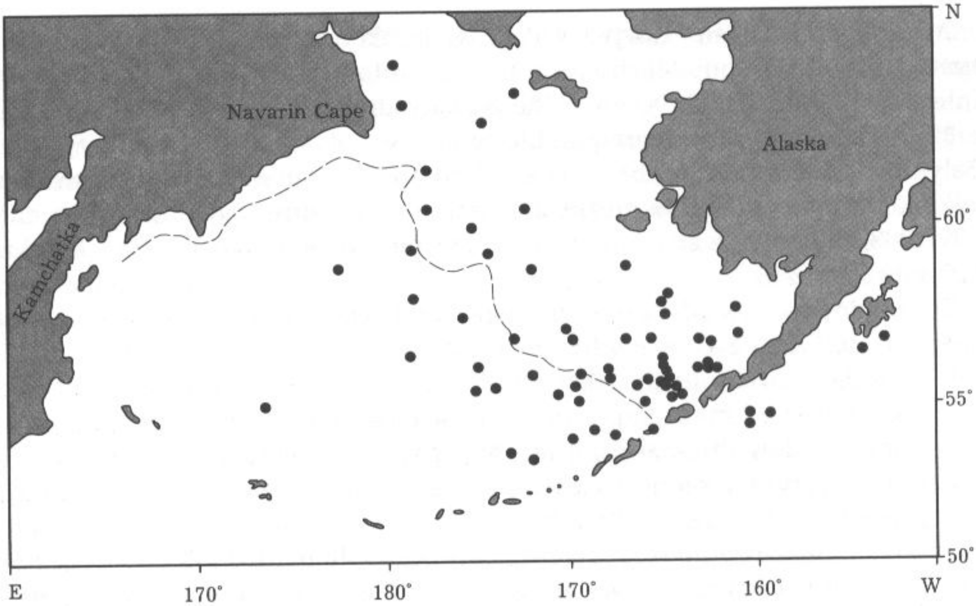


**Fig. 3.3.** Pollock larvae capture sites based on ichthyoplankton surveys in June – August 1963 – 1974 (Haryu, 1980)

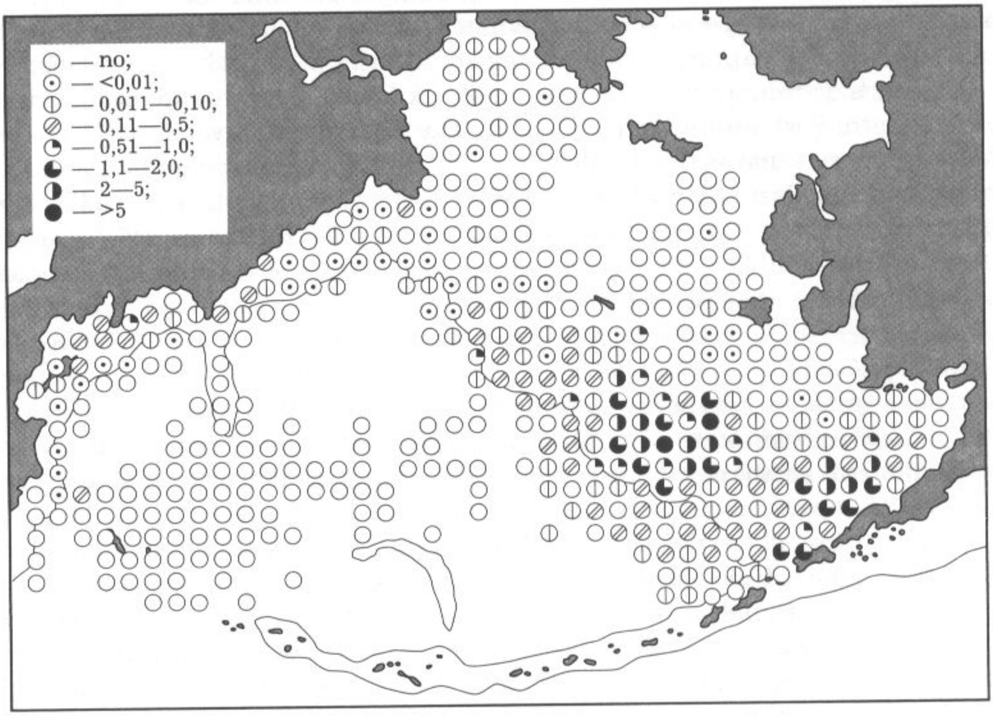


**Fig. 3.4.** Distribution of pollock larvae in the Bering Sea based on ichthyoplankton surveys in March – May 1983 – 1988 (percentage of total abundance, 30' latitude, 1° longitude; Fadeev, 1991)

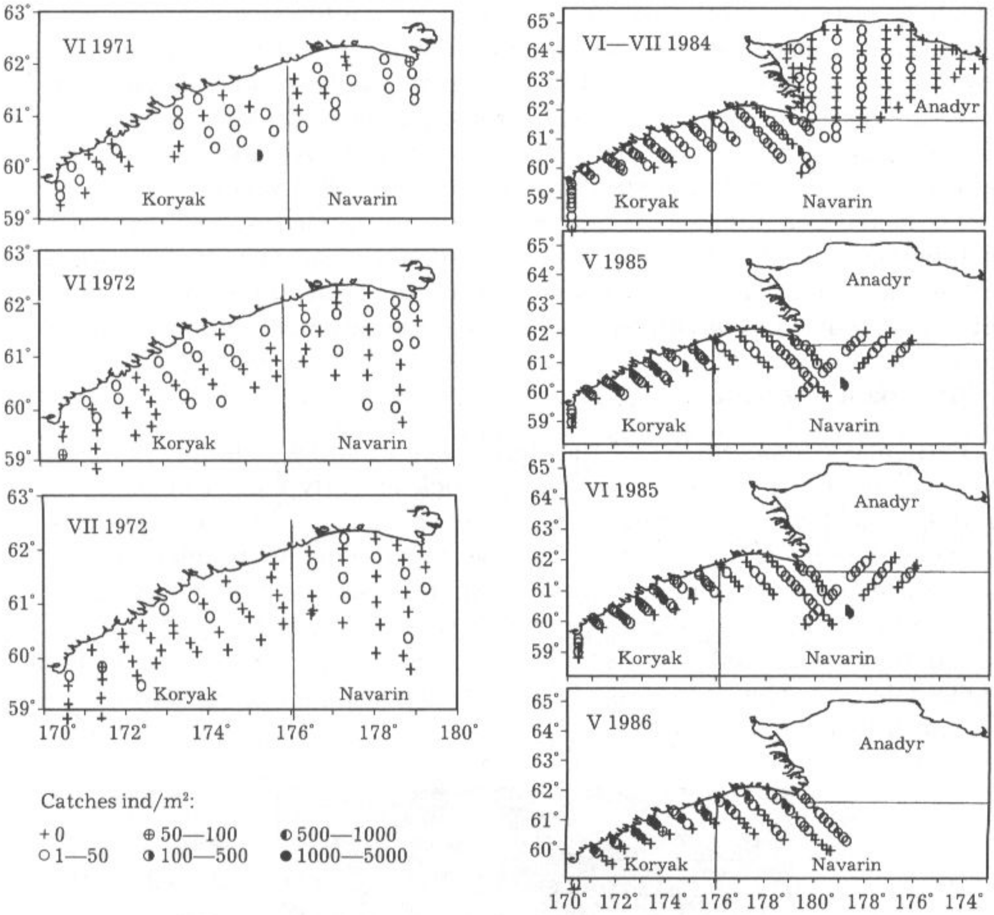


**Fig. 3.5.** Distribution of eggs and larvae of pollock in the Northwest Bering Sea (Balykin, Varkentin, 2002 b)

1980s were not transported by currents from the southeastern shelf, but developed from eggs produced in the high seas. However, at present time it is identify that there is virtually no spawning of pollock in the Aleutian basin. Pollock larvae, which is found there originates from shelf waters of the Bering Sea and, as a rule, is later to die (Suzuki, 1976; Okada, 1977; Yoshida, 1978; Dawson 1989 b; Dell' Arciprete, 1992; Kotenev, 1995; Bailey et al., 1999 b). It is confirmed, among other things, by the complete absence of pollock in the deepwater part of the sea at present (Glubokov, 2004).

The time of spawning is specific for each of these aggregations. The St.Matthew and Koryak aggregations, probably, have not yearly spawning (Fig. 3.1). Absence of temporarily stable spawning grounds in the St.Matthew and Koryak regions indicates that there are migrants from adjacent waters, which do not form there (like in the central part of the sea) independent populations. It is also possible that organization of annual ichthyoplankton surveys in the St.Matthew and Koryak regions precisely in time of spawning will allow us to determine presence and intensity of pollock reproduction in these two regions in the 21st century; this will undoubtedly influence our perceptions about the population structure of the Bering Sea pollock.

The maximum number of eggs in all areas of the Bering Sea was registered in the 1980s. At the turn of the century, there was a change in the relative importance of spawning grounds: that of the Navarin spawning grounds increased, while the Olyutor-Karagin spawning grounds got less prominent.

### Abundance of year-classes

Particular characteristics of the Bering Sea biotopes determine strength of year-classes and survival of juvenile pollock at early stages of ontogenesis. In 1999—2002, with the objective to assess specifics and success of the North Bering Sea pollock reproduction we have made eight recruitment surveys in four consecutive years (2 surveys a year). The Navarin pollock year-class of 2000 had the largest abundance among all year-classes in 1997—2002 (Fig. 3.6). Its maximum recorded abundance in the area of 11,028 square miles totaled 17,699 mln. ind. The year-class of 2001 was the second among the most abundant with its 8,065 mln. ind.

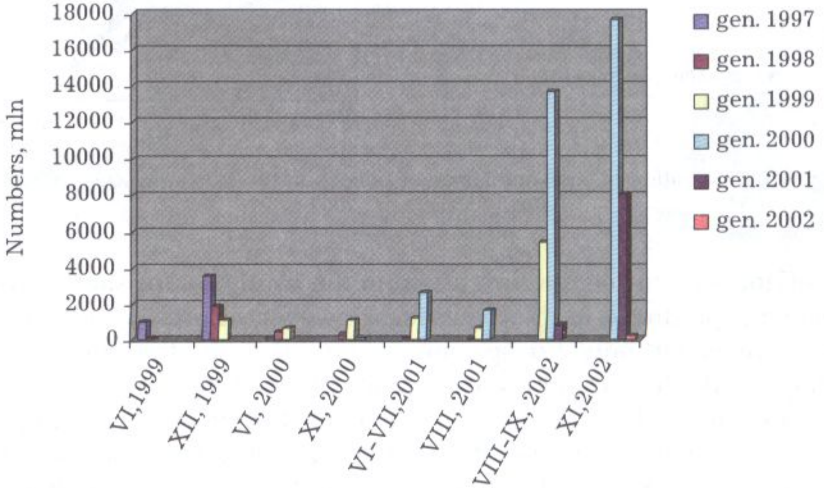


**Fig. 3.6.** Number of juvenile pollock in Navarin region in area of 11028 mile$^2$

Comparison of strtength of the pollock year-classes in the Navarin region and the East Bering Sea shows a big difference between these two regions.

Thus, in August-October 1997, $5.31 \cdot 10^9$ yearlings were recorded in Anadyr

Gulf and adjacent waters (Pavlychev et al., 1999; Stepanenko, 2001 a). The survey made in December 1999 showed that, abundance of that year-class in the area of 11,028 square miles totaled 3,52•$10^9$ ind. (Glubokov, Norvillo, 2002). If we use these data in reverse estimation of abundance and consider natural mortality rate of 30% for the age group of 2+ and 45 % for the age group of 1+ (Wespestad, Terry, 1984), abundance of that year-class (when yearlings) was 9,12•$10^9$ ind. Consequently, we could say that abundance of the 1997 year-class of the North Bering Sea pollock was greater than the average long-term value.

At the same time the spawning biomass and intensity registered in principal spawning grounds of the East Bering Sea pollock population were relatively small in 1997. Echointegration trawl survey indicated that in 1997, biomass of the spawning stock in the southeast Aleutian basin was the minimal (0,34 mln. t) for the period of 1988–1997 (Honkalento, Williamson, 1997). In late August–October, there were no significant concentrations of yearlings southeast of the northern edge of the Zhemchug canyon, including shelf waters off the Pribiloff Islands. In that year yearlings were numerous only in waters to the north of 58°00′ N up to Anadyr Gulf (Stepanenko, 2001 a). Standard surveys made in 1998 revealed that the absolute abundance of yearlings from the 1997 generation was low (Ianelli et al., 1998; Stepanenko, 2001 b). This was also confirmed by recruitment surveys made by the Hokkaido University in the Northeast and East Bering Sea (R/V *Oshoro Maru*) in 1995–1997 (Willson, Brodeur, 1998).

The year-class of 1998 was a great contrast. That year was marked by an intensive spawning on the southeast shelf and significant concentrations of yearlings from this generation (Stepanenko, 2001 a). Russian juvenile surveys indicated that the 1998 generation of the Navarin pollock was 1.87 less abundant than the maximum recorded abundance of the 1997 year-class (Glubokov, 2003). There were no signs of increase in abundance of this northern generation neither at the age of 2+, nor at the age of 3+.

The Navarin pollock year-class of 2000 was called abundant already in late June early July, 2001, while echointegration trawl surveys made by the AFSC (2000 and 2002) did not single it out from other pollock generations in the Northeast and East Bering Sea (Annual conferences.., 2004).

These examples illustrate well the modern absence of significant migrations of the East Bering Sea pollock to the north at early ontogenetic stages: numerous generations of pollock produced on the East Bering Sea shelf, subsequently, later did not become abundant in the Navarin region, and vice versa. Data on abundance of pollock generations in various regions of the Bering Sea confirm our hypothesis that the northern stocks are formed by individuals originated in the Navarin spawning grounds.

On comparison of abundance data for pollock embryos, larvae, and yearlings, scientists from KamchatNIRO arrived at the same conclusion (Balykin, Varkentin, 2002 b). Thus, in 1985, catches of pollock eggs in Anadyr Gulf were poor, and there was no fry in these waters in autumn. The 1985 survey showed that abundance of eggs and larvae totaled $3.79 \cdot 10^{12}$ ind. and there were records of $13.90 \cdot 10^{6}$ yearlings. If we double the egg number taking into consideration spawning production after the end of the survey (Balykin, Varkentin, 2002 b) and apply the catchability coefficient of 0.1 (for young fish) (Shuntov et al., 1988), we shall obtain the survival rate for an embryo until the yearling age totaling 0,0018% (Balykin, Varkentin, 2002 b), which is within the survival range for pollock and other gadids (Zhukinsky, 1986; Hollowed et al., 1996). P.A.Balykin and A.I.Varkentin (2002 b) believe that one could arrive at the same conclusion using similar data on 1987 from book which was written by N.S.Fadeev (1990b). If there had been considerable juvenile migrations (passive or active) to the north, the estimated survival in the Navarin region should have exceeded the standard value (i.e. recorded abundance of fish could be low when made at the early ontogenetic stages, but it could increase as a result of migrations at later stages of development). This could lead to overestimation of the survival rate for the Navarin region pollock and the more fish migrate here from other regions the larger is the overestimation.

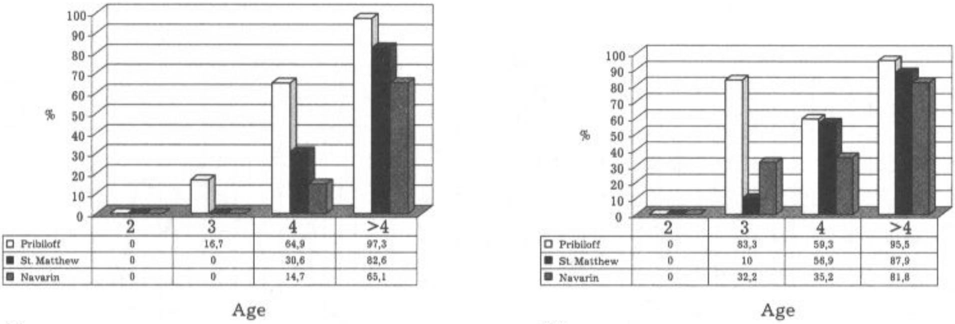
### Maturation rate

Maturation rate has a great impact on determination of life strategy of the species and its populations, particularly on the population fecundity. Habitat conditions drive each population to develop its adaptive peculiar reproduction features including the mean size of maturation (Smith, 1981).

In the North Bering Sea and the Olyutor Bay in 1976, half males and females pollock matured when 37.0 cm and 35.2 cm in length, respectively. In comparison, the majority of males in the eastern part of the sea matured when they were 6 cm shorter and females — when they were 1 cm shorter (Bakkala, Smith, 1978; Smith, 1979; Serobaba, 1979; Megrey, 1989 a).

Our data suggest that there is a latitudinal variability in the pollock maturation rates along the North and East Bering Sea shelf and slope: fish in the north mature later than that in the south (Fig. 3.6). Thus, in 2004, first mature females in the Pribiloff region were three years old and 64.9% of females were mature at age 4+. Meanwhile, in the St.Matthew region, which was located northward, only 30.6 % of females were mature at age 4+. Females of the most northerly pollock schools (the Navarin pollock) underwent mass maturation at age 5+. No females at the age of 3+ were mature in either of the northern regions (the Navarin and St.Matthew regions) (Fig. 3.7 a).

The Pribiloff male pollock had mass maturation at the age of 3+ (83.3 %),



|  | 2 | 3 | 4 | >4 |
|---|---|---|---|---|
| ☐ Pribiloff | 0 | 16,7 | 64,9 | 97,3 |
| ■ St. Matthew | 0 | 0 | 30,6 | 82,6 |
| ▨ Navarin | 0 | 0 | 14,7 | 65,1 |

(a)

|  | 2 | 3 | 4 | >4 |
|---|---|---|---|---|
| ☐ Pribiloff | 0 | 83,3 | 59,3 | 95,5 |
| ■ St. Matthew | 0 | 10 | 56,9 | 87,9 |
| ▨ Navarin | 0 | 32,2 | 35,2 | 81,8 |

(b)

**Fig. 3.7.** Share of mature females (*a*) and males (*b*) of pollock in various areas of the North and East Bering Sea, 2004 (by age)

while the share of the Navarin matured males even at age 4+ hardly exceeded 1/3 (Fig. 3.6, *b*). Like females, males from the St.Matthew region matured slower than their neighbors from the Pribiloff region, though quicker than those in the Navarin pollock.

In warmer regions (the Pribiloff and St.Matthew), maturation would occur earlier than in the cold Navarin region, only if the Navarin pollock did not have mass and long migrations to the south and back. The obtained differences in maturation rates of pollock from the Navarin, Pribiloff, and St.Matthew regions confirm insignificance of pollock migrations along the East Bering Sea shelf identified us through analysis of season by season distribution (Chapter 2).

Figure 3.8 and Table 3.2 summarize data on maturation rates of the North and West Bering Sea pollock collected during the VNIRO, KamchatNIRO, and TINRO-center joint studies, 1999 – 2002 (Glubokov, 2005).

Empirical curves of maturation demonstrate a zigzag pattern probably reflecting maturation rates for various age groups. These unsmoothed curves of maturation reveal peculiarities of the process. Maturation curves for the Navarin male pollock have their special, unique pattern. The smallest firstly maturing individuals in the North and West Bering Sea were found in the Navarin region: males were >25 cm long, and females > 31 cm long. In 2000 – 2001, 50% of males matured when 29 cm long. It is interesting that in the size range of 29 – 43 cm, portion of mature fish was less than for smaller ones (Fig. 3.8) (Glubokov et al., 2002). The smoothed curve of maturation was horizontal in this size range for Navarin pollock. Neither females, nor males from other surveyed regions had not such a maturation pattern, their curves were always ascending. In the Navarin region, males and females <42 cm in length matured quicker, than in the Koryak waters and Olyutor Bay. The share of mature pollock of larger size was almost the same in all the surveyed regions.

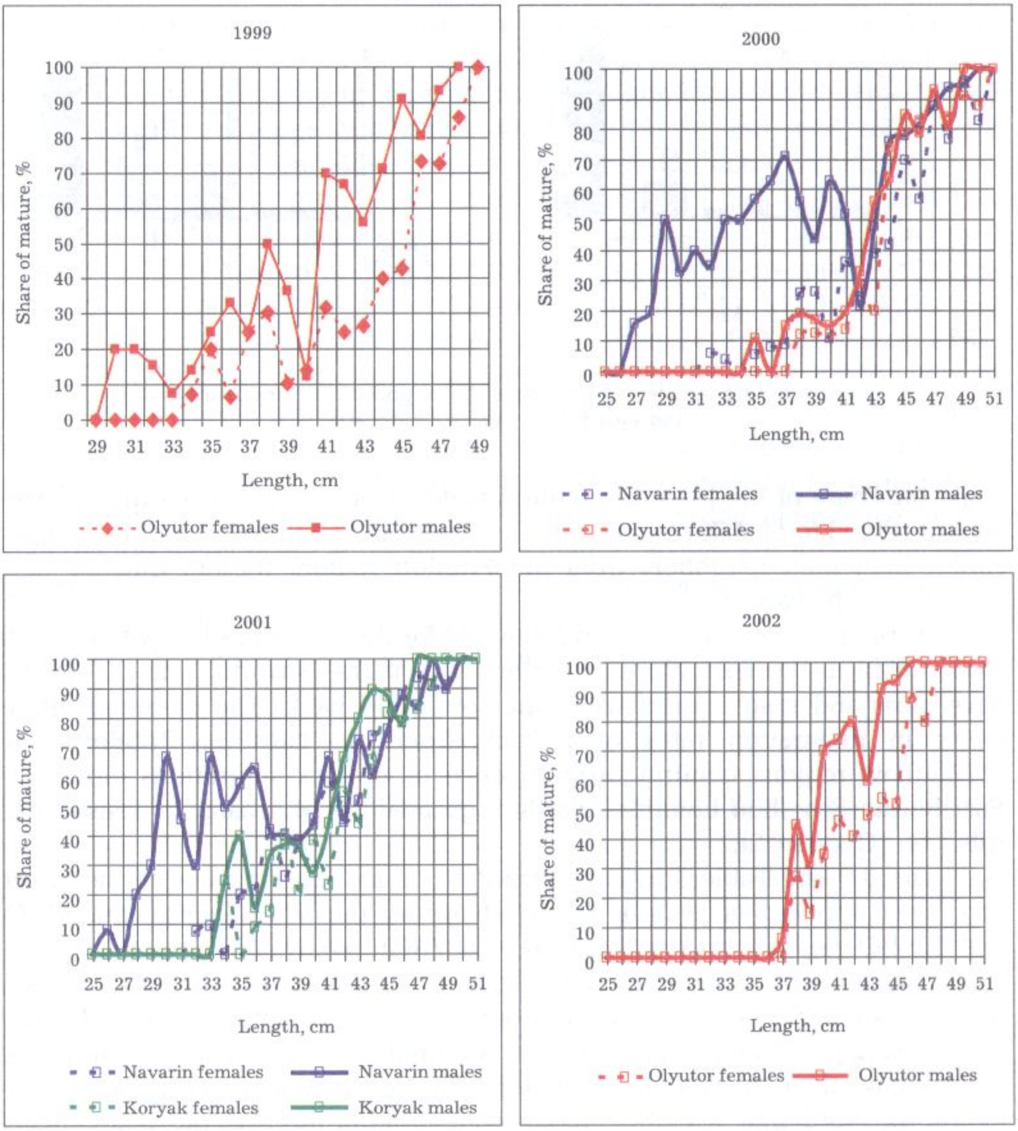


**Fig. 3.8.** North and West Bering Sea pollock ogyvas, by areas (authores' data)

Peculiarities of pollock maturation in the northernmost region of the Bering Sea (the Navarin region) are likely to be of adaptive nature. Compared to the southern aggregations, the Navarin pollock has a shorter feeding period and, consequently, its spawning success depends more on climate and oceanic conditions in a particular year (in cold years yearlings could not grow large enough to survive the wintertime). Therefore, the stock needs some 'insurance' against a bad year and part of the northern male pollock starts to mature

**Table 3.2.** Length of Bering Sea pollock at which 50% fish mature, by region and year

| Year | Olyutor Bay | | Koryak region | | Navarin region | |
|---|---|---|---|---|---|---|
| | males | females | males | females | males | females |
| 1999 | 38, 40 – 41 | 45 – 46 | – | – | – | – |
| 2000 | 42 – 43 | 43 – 44 | – | – | 29, 33 – 39,<br>40, 43 – 44 | 44 – 45 |
| 2001 | – | – | 41 – 42 | 41 – 44 | 29 – 31,<br>32 – 37,<br>40 – 43 | 40 – 43 |
| 2002 | 39 – 40 | 43 – 44 | – | – | – | – |

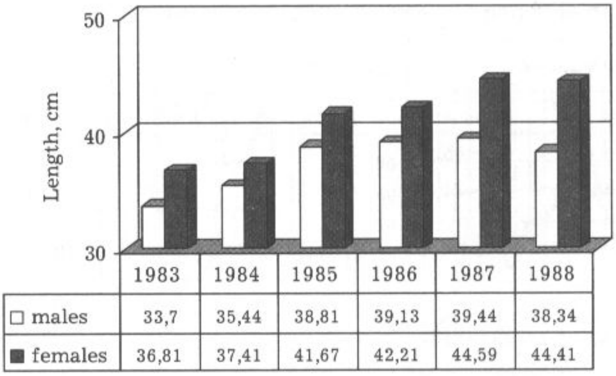
when 29 cm in length, and females – when 35 – 37 cm in length to increase the population fecundity. On the other hand, as was shown above, maturation rates in the northern pollock aggregations are lower than in the southern ones.

Though we could not plot maturation curves for pollock in Olyutor Bay and in the Koryak waters for the same year, data comparison shows that males, and especially females, matured earlier in the latter region than in the former one (Table 3.2). This difference was earlier highlighted by Balykin (1986, 2003).

Comparison of data on maturation size with those on stock abundance indicates that in years of high abundance maturation occurs when fish grows to a larger size than in periods of low abundance. Thus, in years of high abundance (1988), half of the eastern stock matured when males were 34 – 35 cm long and females – 37 – 38 cm long (Fadeyev, 1989 b), while during periods of low abundance (the 1970s) mass maturation occurred when males and females were 31 – 32 cm and 34 – 35 cm in length, respectively (Bakkala, Smith, 1978; Smith, 1979; Megrey, 1989 a; Serobaba, 1979). Similar pattern was observed in Gulf of Alaska in the 1980s (Fig. 3.9): in 1983 – 1988, the period of the pollock biomass growth, size at maturation increased by 3 cm for males and almost by 6 cm for females (Megrey, 1989 a).

In the central part of the Bering Sea in 1970s, majority of male and female pollock in attained maturity when they were 35 cm and 39 cm long, respectively (Yoshida, Yoon, 1981), in the 1980s, 50% of males and 30% of females were mature when 42 cm long (Fisheries Agency Japan, 1984; Yamaguchi, 1984).

Variations in size at maturation is likely to be a reaction which helps maintain the population homeostasis: in years of high abundance, population fecundity decreases as a result of increase in the maturing fish size, while low abundance brings about the opposite correlation.



| | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 |
|---|---|---|---|---|---|---|
| □ males | 33,7 | 35,44 | 38,81 | 39,13 | 39,44 | 38,34 |
| ■ females | 36,81 | 37,41 | 41,67 | 42,21 | 44,59 | 44,41 |

**Fig. 3.9.** Length at 50% maturation of male and female pollock from the Gulf of Alaska, by year (after Megrey, 1989)

Summarizing the discussion concerning pollock reproduction, we could suggest the following:

– in the Bering Sea, stable annual spawning characterizes the Olyutor-Karagin, Navarin, Pribiloff, and Unimak-Bristol aggregations; and

– emergence of abundant year-classes and size at maturation are specific for each aggregation.

Identified differentiations in reproduction of the West, North, and East Bering Sea pollock indicate that fish from these aggregations have adapted to particular habitat conditions in these areas.

# CHAPTER 4

## SPATIAL PECULIARITIES OF THE SIZE-AT-AGE STRUCTURE OF THE BERING SEA POLLOCK

In previous chapters we have shown: that pollock aggregations are spatially relate to particular regions of the Bering Sea; each of this region is characterized by stable annual spawning and specific of year-class strength. Another proof of the existence of temporarily stable self-regulating pollock groupings could be yield by studies of peculiarities of their size-at-age structure developing under the influence of unique statios.

Using data collected in the1970s – early 1980s, Bakkala and his coauthors (1986) described peculiarities of the pollock size composition in various geographical regions. Thus, in 1972, the Navarin region was dominated by pollock 34–38 cm and 44–56 cm in length. A unimodal length composition with a well-smoothed peak in the range from 26–46 cm characterized pollock from the central part and southern periphery of the Zhemchug trench (waters off the Pribiloff Islands). The Unimak pollock length frequency had a pronounced peak in the range of 40–46 cm.

One of the first joint American-Japanese thorough surveys in the Northeast, East, and Central Bering Sea (1979) revealed heterogeneity in the size-at-age composition of pollock. The St.Matthew aggregations was dominated by the 2+ fish (the 1977 generation) 21–23 cm long (Fig. 4.1, *a*). Northwestward of the Pribiloff Islands, small-sized pollock 15-17 cm long at age 1+ (the 1978 generation) prevailed (Fig. 4.1, *b*). Individuals 34–36 cm long at age 3+ (the 1976 year-class) were most abundant to the southeast of the Pribiloff Islands (Fig. 4.1, *c*). The largest pollock was found in waters of the Aleutian Basin dominated by fish at age 6+, 9+, and 10+. In July, size frequency of this aggregation was the shortest: there were no individuals less than 39 cm and more than 54 cm long in catches (Fig. 4.1, *d*) (Traynor, Nelson, 1985; Okada, Yamaguchi, 1985; Janusz, Linkowski, 1989).

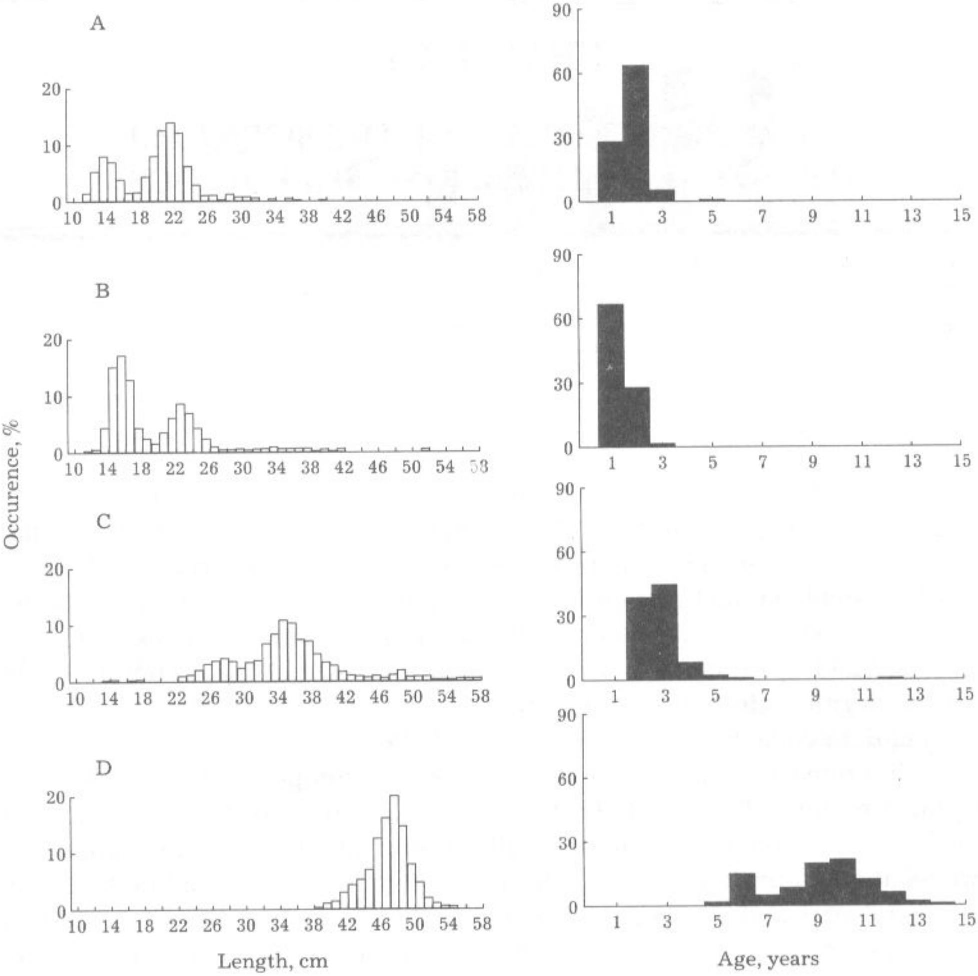


**Fig. 4.1.** Size and age of East Bering Sea pollock based on the USA July 1979 echointegration trawl survey. *A* – St.Matthew area; *B* – north of Pribiloffs islands; *C* – south of Pribiloffs islands; *D* – Aleutian basin (Traynor, Nelson, 1985)

The Soviet summer surveys (1979–1981) showed a great diversity in the size-at-age composition of pollock in the St.Matthew, Pribiloff, and Unimak regions. Thus, in the summer of 1980, catches from the Unimak region were dominated by pollock 28–32 cm, 34–38 cm, and 50–54 cm long. Individuals of 2+ (the 1978 generation) were the most abundant, pollock of the four subsequent year-classes made approximately equal parts (Fig. 4.2, *a*). In the Pribiloff region pollock demonstrated a unimodal size distribution with a peak in the range from 28–34 cm. As to the age groups, there was an absolute predominance of fish at age 3+ (the 1977 generation). Portion of pollock at age 2+, 4+, and 5+ were equal (Fig. 4.2, *b*). The St.Matthew pollock stock was characterized by a more smoothed and wider peak in the length frequencies, compared to the Pribiloff pollock. As for the St.Matthew pollock, modal length frequencies were 28 – 38 cm. Pollock at the age of 3+ and 4+ (year-classes of 1977 and 1976) prevailed in the age composition (Fig. 4.2, *c*) (Moiseev, 1983). In the next 1981 year, in the Unimak region pollock 36–40 cm long at age 5+ prevailed (the 1976 generation). Fishes 28–64 cm long at age 3+ – 9+ were equally abundant in the Pribiloff region. There were two small peaks

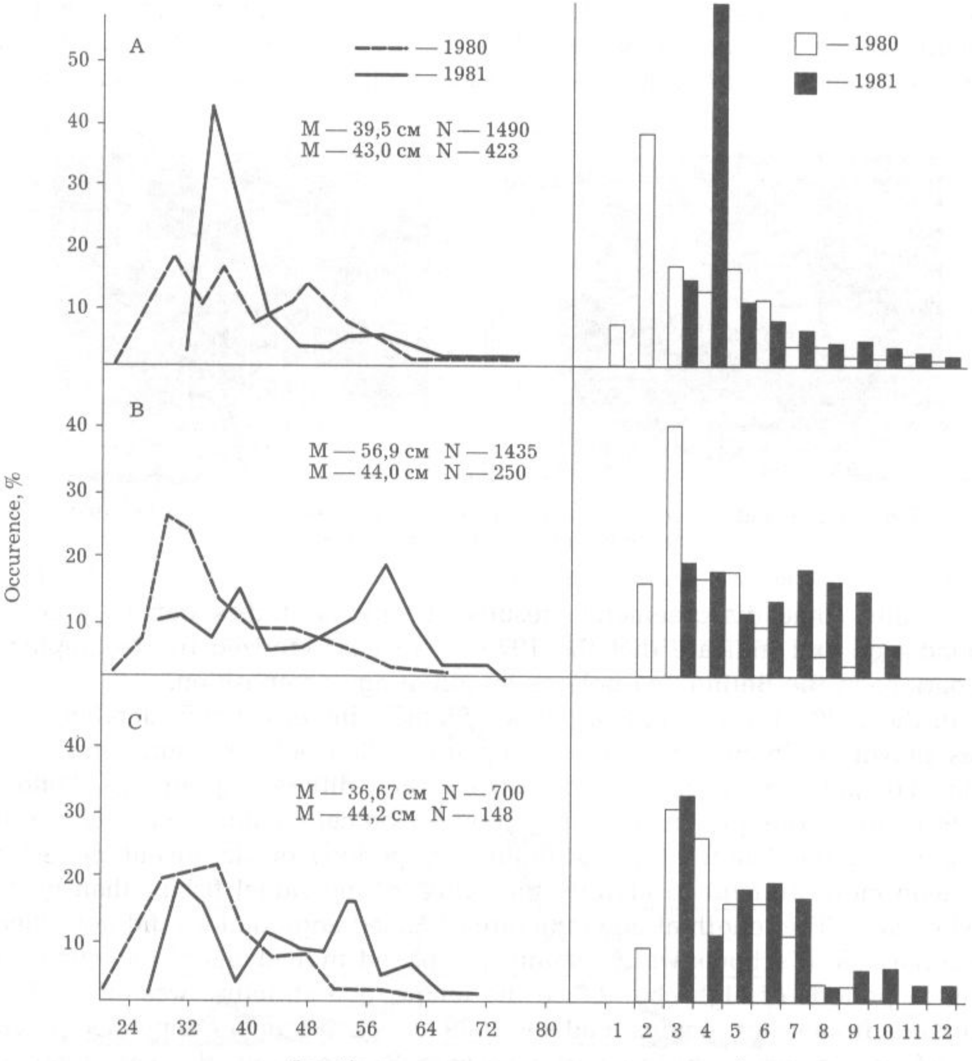


**Fig. 4.2.** Size and age composition of pollock catches in the East Bering Sea in 1980 – 1981 (*A* – Unimak area, *B* – Pribiloff area, *C* – St. Matthew area) (Moiseev, 1983)

in the range from 40 – 62 cm length frequencies. In the St.Matthew region, pollock 30 – 36 cm long and 42 – 58 cm long was most abundant. Most prominent in the age composition were fishes at age 3+ (the 1978 generation), though individuals at age 5+, 6+, 7+ were also rather numerous (Fig. 4.2) (Moiseev, 1983).

In the western part of the sea the pollock length-at-age composition was quite unique. In 1979, this pollock was dominated by the 1976 year-class (32.1%) (Fig. 4.3). Generations of 1973 and 1972 were also abundant (16.5% and 16.0%, respectively). In 1980 and 1981, the 1977 generation became predominant with its share of 36.0% and 38.1%, respectively. The 1976 year-class was the second abundant with 14.3% (1980) and 19.1% (1981) (Balykin, 1989).

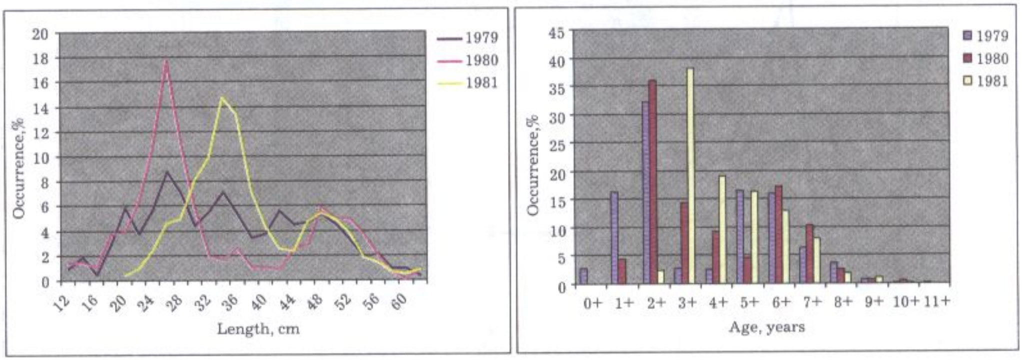


**Fig. 4.3.** Size and age composition of the West Bering Sea pollock in 1979 – 1981 (according to data of Balykin, 1989)

Despite some disagreements, results of various studies generally correspond well and indicate that the 1970s were characterized by geographical variations in the Bering Sea pollock length-at-age composition.

In the 1980s, the Bering Sea pollock biomass increased considerably. As it was shown in Chapter 2, such increase intensified pollock migrations determine competition for space and food between different groupings. Pollock from various aggregations began to mix. Biological changes led *inter alia* to changes in the length-at-age structure. In periods of significant mixing it became more difficult to identify the origin of individual fishes, than in the last decade. The length-at-age structure of mixed aggregations did not reflect peculiarities of schools which mainly comprised individuals of the same origin. In periods of high abundance the length/age structure was affected by migrants from other regions (Fadeev, 1989 a), which number depended on climate/oceanic conditions in a particular year. Besides, since the early 1980s all the Bering Sea pollock populations have been dominated by fish from the extremely strong year-class of 1978 (Moiseev, 1983; Traynor, Nelson, 1985; Okada, Yamaguchi, 1985; Balykin, 1989; Fadeev, 1989 a; Janusz, Linkowski, 1989); this could also smooth out regional variations in the length-at-age composition.

In the 1990s, decrease in the Bering Sea pollock biomass brought about shrinkage of migration routes. The length-at-age composition also changed and again reflected specific features of particular statios. Thus, comparison of the length-at-age composition of pollock aggregations in the North and East Bering Sea showed that in the summer of 2004, the Navarin region was dominated by pollock 37 cm, 31 cm, and 23 cm in length (respectively, generations of 2000, 2001, and 2002 ), individuals 39 cm long (the 2000 year-class) prevailed in the St.Matthew region, while the Pribiloff waters were dominated by pollock 44 cm and 41 cm long (the 1999 and 2000 generations), in Unimak region the dominating group was made of pollock 54 cm long (apparently the 1996 generation) and 44 cm long (apparently the 1999 generation) (data of echointegration trawl survey made by the AFSC, in which one of the authors participated) (Fig. 4.4, 4.5) (Glubokov, 2005).

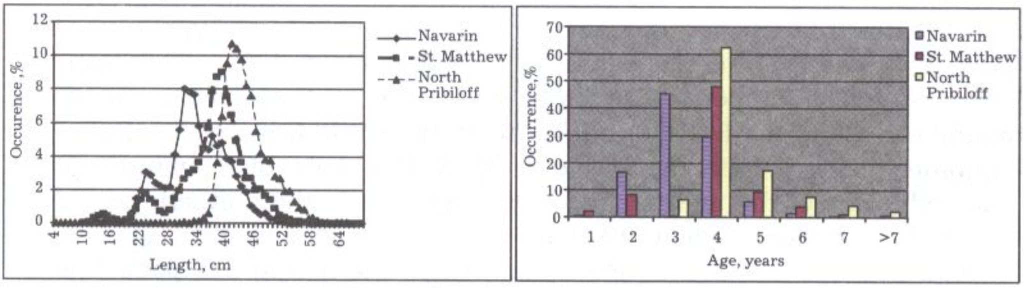


**Fig. 4.4.** Size and age composition of the North and East Bering Sea pollock, July 2004

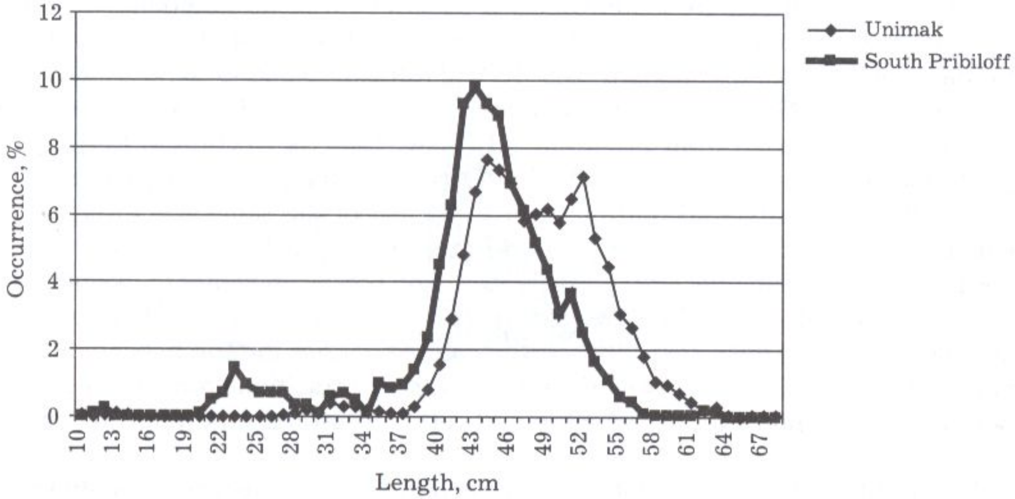


**Fig. 4.5.** Size composition of pollock from the Southeast Bering Sea, June 2004

We have also found a difference in size composition between pollock catches taken in the North and West Bering Sea. Thus, according to data obtained during surveys aboard the MRT *Shursha* and the R/V *Professor Kaganovskiy* (August—October, 1996) the Navarin region was mainly occupied by individuals 16—19 cm in length and 33—36 cm in length (i.e. generations of 1995 and 1993); in the Olyutor-Navarin (Koryak) region there were two dominating groups: one with the length of 21 cm and the other with the length of 40—45 cm (probably generations of 1995 and 1992); Olyutor Bay was dominated by pollock 18 cm long (the 1995 year-class), 26 cm long (the 1994 year-class), and 38 cm long (obviously generations of 1993—1992) (Fig. 4.6) (Fadeev, 2001).

The above said suggests that spatially isolated pollock groupings of the Bering Sea (the Olyutor-Karagin, Koryak, Navarin, St.Matthew, Pribiloff, and Unimak-Bristol) are characterized by their own specifical length-at-age composition.

The fact that since the 1980s, the Navarin pollock was dominated by juvenile fish was served a good argument for adherents of the hypothesis about pollock migrations from the south to the north (Fadeev, 1989 a; Shuntov et al., 1993). Actually, in periods of high abundance, pollock makes significant migrations along the East Bering Sea shelf. Immature fish are the most active migrants (Note: e.g. in the spring of 1988, the share of immature pollock attained 93.8% of the total aggregation of pollock in the northern part of the St. Matthew region (Fadeev, 1989 a)).

However, the last decade and a half, when the Bering Sea pollock abundance was relatively low, the share of immature fish in the Navarin region did not exceed that in the East Bering Sea and in Olyutor Bay (pollock stocks in these last two regions are acknowledged as stocks with an independent population status which have no migrants from distant regions). Thus, according to data of the survey aboard the R/V *Professor Kaganovskiy* (August—October, 1996), the portion of the pollock 12—30 cm long was 64% in Navarin region (numbers take from the graph) (Fadeev, 1989 a). According to data of joint VNIRO, KamchatNIRO, and TINRO-center surveys, in June-December 1999—2002 the estimated portion of juvenile fish of the same size group varied in the range from 56—76%, making the average of 64% in summer (last decade of June — first decade of September), and 65% — in winter (November—December) (Table 4.1) (Glubokov, 2003). This is a clear indication that, on the average, in 1999—2002, there were no dramatic changes in ratio between juvenile and adult fish in the Navarin region during transition from the feeding period to the wintering one, which could reflect seasonal inflows of juveniles (Table 4.1).

The published data of AFSC summer echointegration survey 1999 showed predominance on the East Bering Sea shelf pollock in the 1—3 year old; their share in the total recorded abundance in the bottom and pelagic layers made 64% (Nikolaev, Stepanenko, 2001).

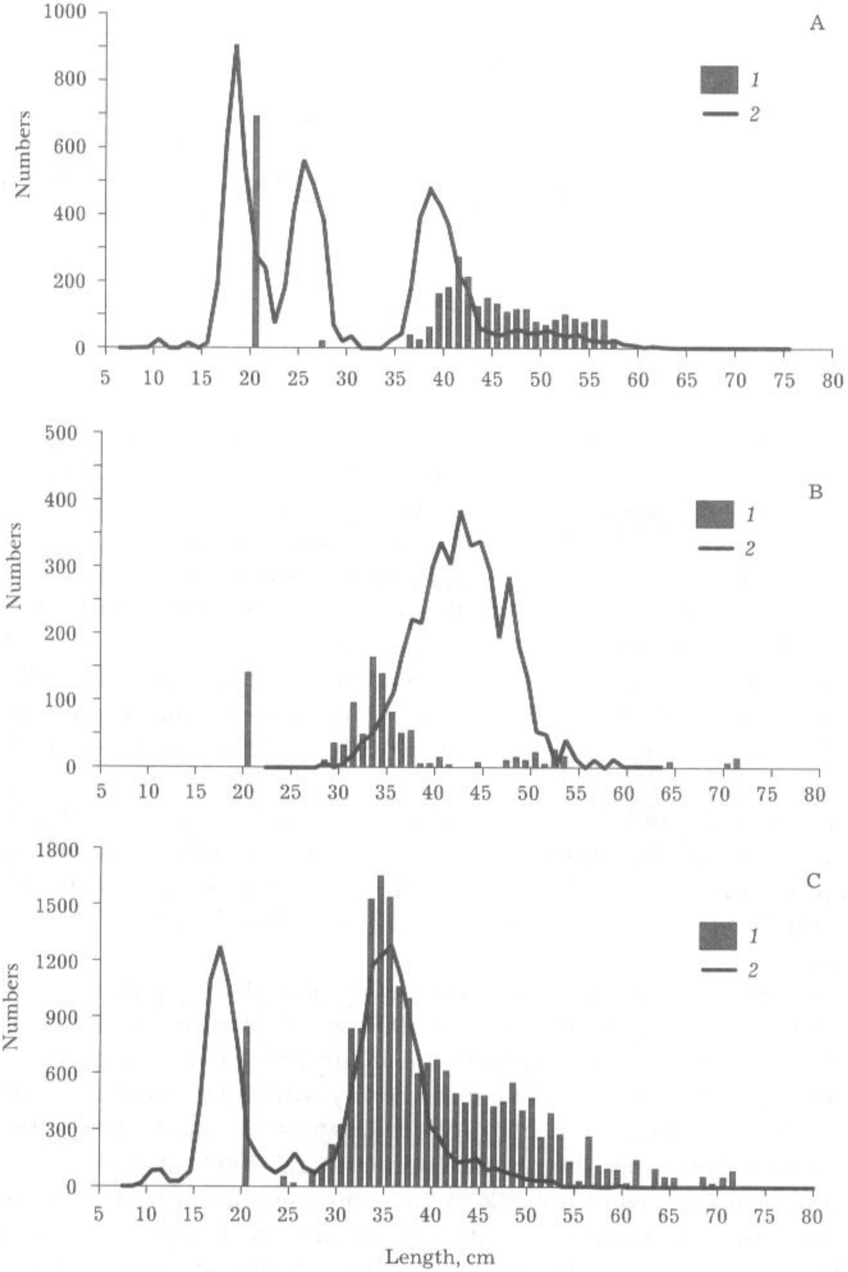


**Fig. 4.6.** Size and age composition of pollock by number ($10^5$) in the Northwest Bering Sea in August – October 1996: *A* – Olyutor Bay; *B* – Olyutor–Navarin area; *C* – Navarin area. *1* – MRT «Shursha»; *2* – R/V «Professor Kaganovskiy» (Fadeev, 2001)

**Table 4.1.** Share of the 12–30 cm pollock in Navarin area, juvenile survey (VNIRO, KamchatNIRO, and TINRO-center)

| Year | Month | Share of the 12–30 cm pollock, % |
|---|---|---|
| 1999 | June | 57 |
|  | December | 76 |
| 2000 | June | 61 |
|  | November | 64 |
| 2001 | June–July | 65 |
| 2002 | August–September | 73 |
|  | November | 56 |

The survey made aboard the R/V *Professor Kaganovskiy* (August–October, 1996) in Olyutor Bay indicated that pollock 12–30 cm in length also made 64% (numbers take from the graph) (Fadeev, 2001).

The same survey in the Koryak region showed that juvenile pollock was rare in catches (Fadeev, 2001). A year later (November–December, 1997) another survey made by the Chukotka affiliate of the TINRO-center with a bottom trawl showed that at 175° E the portion of pollock 19–30 cm long was 11% and catches were dominated by individuals 43–48 in length (27% of the total number) (Datskij et al., 1999). A very small percentage of juveniles and non-yearly spawning indicate that the Koryak pollock aggregations do not form an independent population.

Information collected during several surveys made in one year is extremely important for understanding of rules of the pollock stock formation by seasons. Figures 4.7 and 4.8 illustrate length-at-age data series on the Navarin pollock (the VNIRO studies conducted in accordance with a new science technique).

In June 1999, the Navarin region was mainly occupied by pollock 19–25 cm long and 13–17 cm long (generations of 1997 and 1998, respectively) (Fig. 4.7, *a*; 4.8, *a*). The portion of former generation made 34% of the total stock, while the latter made 21%. The TINRO-center survey, which was made a month and a half later, showed that the portion of 1997 generation made 38% of the total stock (numbers take from the graph) (Borets et al., 2002). It means that there was no significant inflow of pollock of the same generation from other regions during the feeding period. As it was shown in Chapter 2, by winter (December) the majority of the Navarin pollock migrated from shallow waters in Anadyr Gulf and concentrated within the surveyed area (central and southern waters of the Anadyr-Navarin region). In this month in 1999, there was an

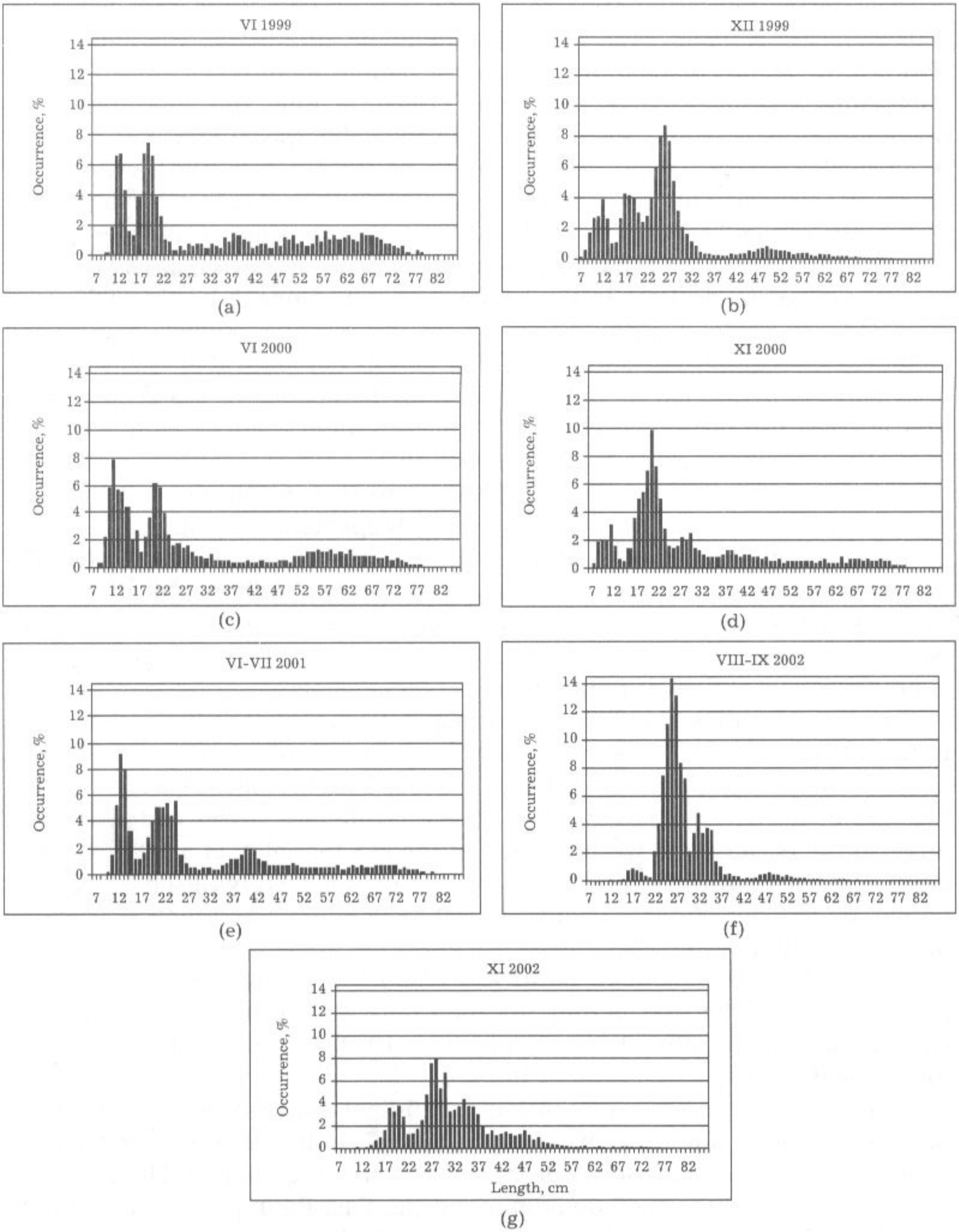


**Fig. 4.7.** Size composition of Navarin pollock based on recruitment bottom trawl surveys by year and season

increase in the portion of the strong year-class of 1997 up to 48%, while the 1998 generation made 24%. The third abundant group was yearlings (15%) (Fig. 4.7, *b*; 4.8, *b*). In 2000 in the Navarin region, there was a shift from one dominating year-class (1997) to another (1999). In June, this age group (with the length of 12 — 18 cm) made 36% of the total abundance (Fig. 4.7, *c*; 4.8, *c*). In November, catches were still dominated by the 1+ fish (48%), which grew up to 19 — 26 cm. The autumnal survey of 2000 was the first to show high abundance of the 2000 generation (Fig. 4.7, *d*; 4.8, *d*). Being small (11 — 15 cm), some yearlings managed to escape from the trawl, and nevertheless their portion in catches made 12%. In the summer of 2001 (June-July) the 2000 year-class (13 — 18 cm in length) made 31% of the Navarin pollock, the second abundant generation was still 1999 (27%, 21 — 27 cm long) (Fig. 4.7, *e*; 4.8, *e*). Both surveys performed in 2002 revealed predominance of the 2000 generation in trawl catches taken from the Navarin region (Fig. 4.7, *f, g*; 4.8, *f, g*). The AFSC summer survey of 2002 showed that in the St. Matthew region, the dominating year class was that of 2001 (more than 60%), and not the 2000 year-class as in the Navarin region (Gritsai, Stepanenko, 2003).

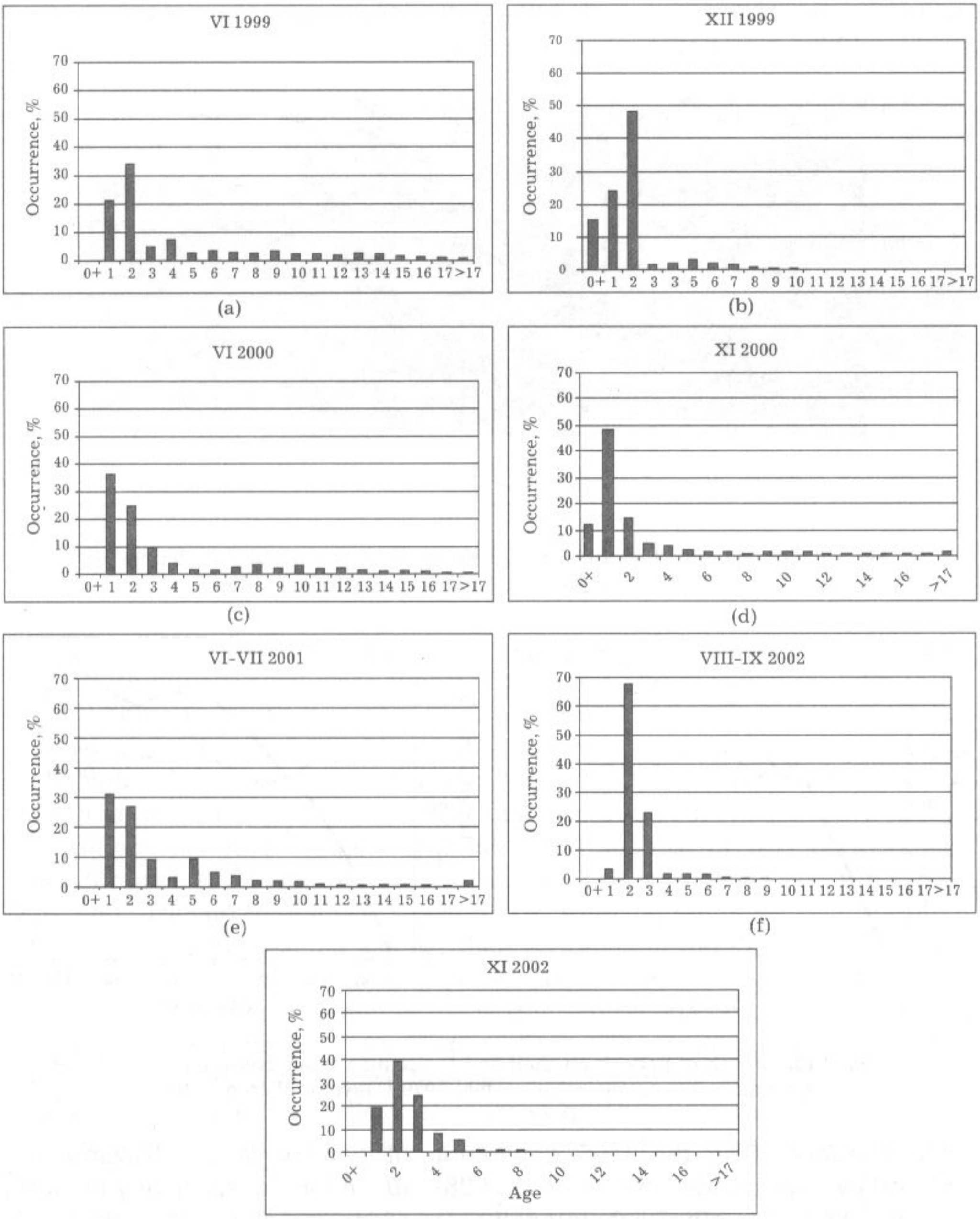
Thus, quantitative analysis of the length-at-age composition of the Navarin pollock stock based on data from repeated surveys confirms peculiarities of the seasonal redistribution identified in Chapter 2, and proves that today the North Bering Sea generally accommodates pollock of all age groups and there is no significant inflow of migrants from other regions.

Specifics of statios of individual fish populations influence the growth rates: in the 1970s — 1980s, the Bering Sea pollock growth rates increased from the north to the south (Fig. 4.9) (Moiseev, 1983; Sasaki, 1989; Dawson, 1989 a; Traynor et al., 1990; Shuntov et al., 1993; Nishimura, 1998) and resembled those in the eastern and western parts of the sea (Shuntov et al., 1993). Slowdown of pollock growth in the north could be explained by a shorter feeding period, dependent on rapid cooling of waters in autumn and their slow warming up in spring.

Pollock from the Aleutian basin was characterized by slow growth, compared to that on the East Bering Sea shelf (Fig. 4.10) (Traynor, Nelson, 1985; Okada, Yamaguchi, 1985; Janusz, Linkowski, 1989), which could be caused by food deficit in deepwater parts of the sea.

At present we observe a persistent latitudinal increase in the Bering Sea pollock length by age from the north to the south. In July — September 1996, commercial catches of pollock from the Navarin region (the TINRO-center monitoring aboard the BRT *Borodino*) and the East Bering Sea included individuals of the same generation which were 33 — 35 cm and 35 — 37 cm long, respectively (Fadeev, Gritsai, 1999).

The AFSC surveys in the East Bering Sea (June 12 — August 03, 1999) showed that northward of the Pribiloff Islands the mean size of pollock at age



(a)
(b)
(c)
(d)
(e)
(f)
(g)

**Fig. 4.8.** Age composition of Navarin pollock, based on recruitment bottom trawl surveys by year and season

1+ was 13 cm and pollock at age 2+ was 23 cm. Our data on the Navarin pollock in the same year revealed that pollock from the same age groups were smaller: 12.8 cm and 17.7 cm, respectively.

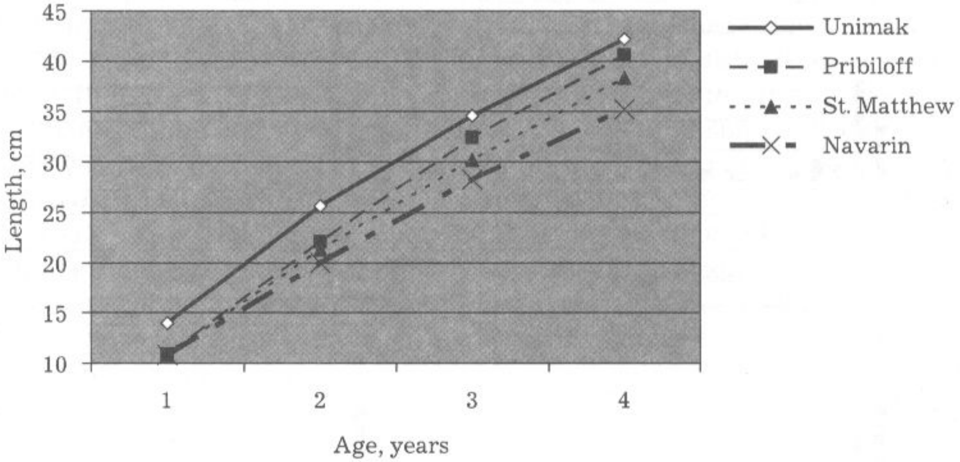


**Fig. 4.9.** Growth of pollock from various areas of the North and East Bering Sea (according to data of Moiseev, 1983)

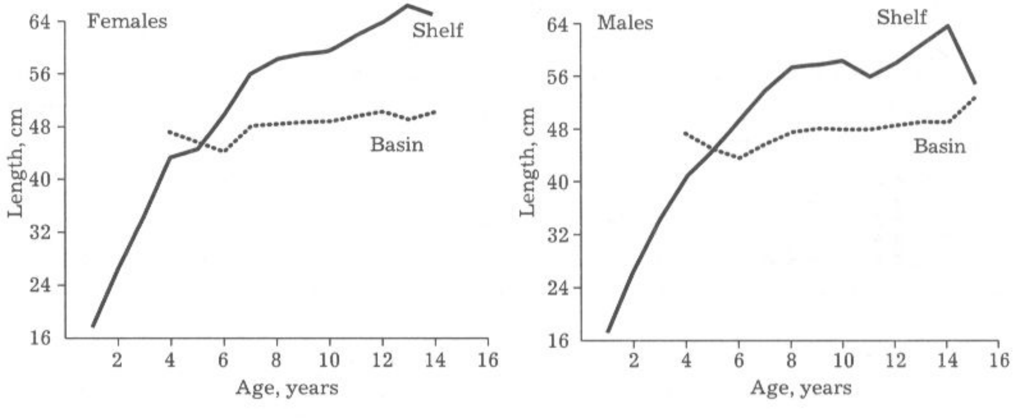


**Fig. 4.10.** Growth of pollock on shelf and in Aleutian basin, based on the USA hydroacoustic survey in June—July 1979 (Traynor, Nelson, 1985)

In October 2000, the 1996 generation of pollock in the Navarin and St.Matthew regions was 36—38 cm and 38—40 cm long, respectively (Fadeev, Gritsai, 2003). The AFSC echointegration trawl surveys (2004) showed that in northern latitudes size of pollock from the same age groups was smaller than in the south (Fig. 4.11). In July, the mean size for the 2000 pollock generation was 38.7 cm in the Navarin region, 39.5 cm — in the St.Matthew region, and 42.0 cm — in the Pribiloff one; individuals of the 2001 year-class in all the three regions were 31.8 cm; 33. 2 cm and 37.2 cm, respectively. The observations of 2004 are very close to the mean size presented by Fadeev and Gritsai (2003) for 2000.

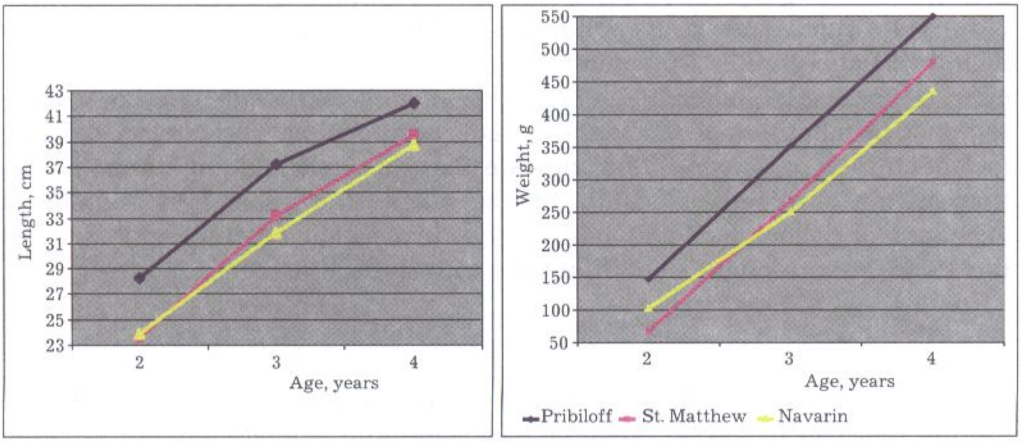


**Fig. 4.11.** Growth of pollock from various areas of the North and East Bering Sea, based on echointegration trawl survey on «Miller Freeman» in July 2004

Meanwhile, in the late 1980s, 0+ from the northern and southern parts of the East Bering Sea shelf were almost of the same size (Nishimura, 1998). Like in the 1980s, at present, size of pollock 0+ do not depend on the location of capture. According to data of the AFSC survey (July, 2004), the mean size of 0+ caught wherever from the Navarin region up to the Pribiloff Islands varied in the range from 2.42 cm – 2.57 cm. There were no statistically significant differences (the Student criterion <1,5) in size of 0+ between the Pribiloff region (2.57 cm), St.Matthew region (2.42 cm), or the Navarin region (2.51 cm). The northernmost, Navarin 0+ were larger than their southern (St.Matthew) neighbors, but smaller than yearlings in the Pribiloff region.

This fact proves that the Bering Sea pollock yearlings do not drift in mass along the East Bering Sea shelf in the northern direction even in years of high abundance and intensive reproduction. Otherwise, yearlings drifted to the north with currents should have been the eldest and the largest.

The West Bering Sea pollock also grows quicker than its northern neighbor. Thus, in 1996, the mean size for the 1995 year-class was 17.7 cm in the Navarin region and 20.7 cm in Olyutor Bay (Buslov, Varkentin, 2001). The very same year, pollock from the prevailed 1992 generation caught northeastward of 178° E was 31–33 cm in length, while southwestward of 176° E fish from the same generation was 34–36 cm long. In September, pollock of this age group attained 31–35 cm in length in the north, and 37–41 cm in the west (Varkentin, 1998).

To summarize, the following regions of the Bering Sea: the Olyutor-Karagin, Koryak, Navarin, St.Matthew, Pribiloff, and Unimak regions, as well as the Aleutian basin demonstrate their specific length-at-age structure and growth rates of pollock. In all the mentioned regions, except the Aleutian basin (as a rule, there is no pollock of younger age groups), pollock stocks include all age groups. Abundance of generations and pollock survival, especially at the early stages of ontogenesis, as well as growth rates determine regional peculiarities of the length-at-age composition. Diversity of the pollock length-at-age composition indicate that there are unique habitat conditions within each region (statio), on the other hand, there is no significant exchange of pollock between these regions (except the central Bering Sea and the 1980s), which could smooth out the observed differences.

# CHAPTER 5

## SOME ASPECTS OF THE BERING SEA POLLOCK PHYSIOLOGY

Studies of the adaptations to habitat conditions are an important stage of identification of individual groupings which inhabit particular biotopes during long time.

N.V.Timofeev-Resovskiy with coauthors distinguished a special branch of phenetics, population morphophysiology, «aiming at a more or less detailed study of the population structure, statics and dynamics for various species of living organisms through identification and classification of any their morphophysiological features» (Timofeev-Resovskiy et al., 1973), because groups of individuals living in similar conditions should react to changes in their environment in a similar manner (Parsons, 1995).

Indices of the organs present a set of indicators of metabolic processes which continue in the organism, while changes of these indices at the ontogenetic stage or in different seasons reflect general peculiarities of plastic and generative metabolism.

The most important morphophysiological indicators are relative weights of gonads and liver (these organs participate in plastic and generative metabolism) and spleen (an essential hemopoietic organ, which plays an important role in metabolism), as well as cardiologic index reflecting intensity of motor activity and blood circulation.

### Cubic condition factor

Biotopes (statios) determine time, rates and direction of metabolism developing *inter alia* peculiarities of seasonal, interannual, and ontogenetic dynamics of the cubic condition factor (CCF).

There are few publications on the mature pollock cubic condition factor in various regions of the Bering Sea. Thus, according to data on the 1970s, in June, the central Bering Sea pollock was characterized by a less cubic condition factor than on the shelf. In July, cubic condition factor of the Aleutian basin pollock was close to that of pollock concentrated to the northwest of the Pribiloff Islands and was quite different from cubic condition factor of pollock from the southeast part of the Bering Sea shelf (Sasaki, 1989).

Studies made simultaneously in the Navarin, Koryak, and Olyutor regions showed considerable variations of the Clark cubic condition factor by area (Fig. 5.1, Annex 1.1). The Koryak pollock was in a better nutritional state than its neighbors from the other two regions in all seasons in 1999–2002. Variations of CCF in 2000–2002 were statistically significant. The Navarin pollock was in the poorest state (except 1998).

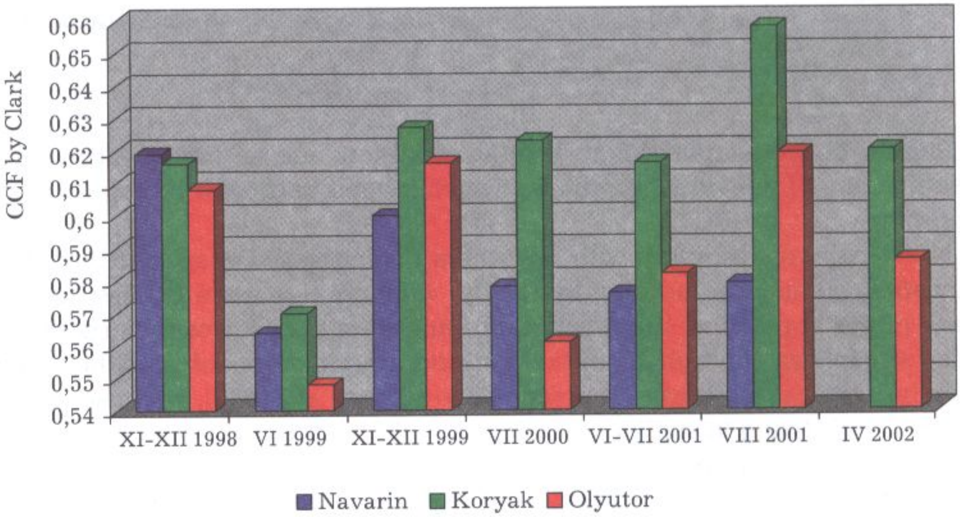


**Fig. 5.1.** CCF by Clark in North and West Bering Sea mature pollock, by area and year

There were no significant seasonal variations in CCF in Koryak pollock (as a rule, deviations were no more than 6.4%). The Navarin pollock demonstrated larger variations in the cubic condition factor (6.9%) but not significant too. Seasonal variations in the CCF attained the maximum amplitude in the Olyutor Bay pollock (11.0%).

Interannual variations of this indicator were also minimum in the Koryak pollock: in winter they made 1.8%, while in summer (except 1999) the deviation was 1.1%. The summer CCF in the Olyutor pollock was increasing during the surveyed period. Limiting values differ by 13.0%.

In the northern and eastern parts of the sea the cubic condition factor also varied from region to region. The minimum value characterized the Navarin pollock, while the maximum one was observed in the St.Matthew pollock (Fig. 5.2).

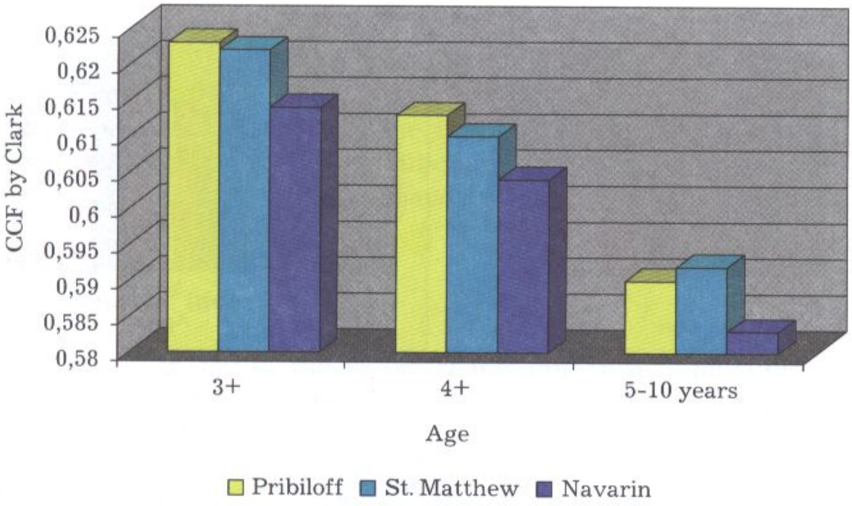


**Fig. 5.2.** CCF by Clark in North and East Bering Sea pollock, by area and age in July 2004

Regional peculiarities of the CCF were also observed in immature fish. Our surveys in the Northwest Bering Sea showed that both in summer and in autumn-winter, two or four-year-old pollock had the maximum cubic condition factor in the Koryak region and the minimum in the Navarin one (Fig. 5.3, 5.4).

The cubic condition factor value in the Olyutor Bay immature pollock was between those in the Koryak immature pollock and in the Navarin pollock (Fig. 5.3).

In the eastern part of the sea the maximum cubic condition factor in immature pollock were found in the Pribiloff region, while the minimum value characterized the Navarin juveniles (Fig. 5.2).

Nucleuses of cold in the Olyutor and Navarin regions are likely to be among causes of a poor nutritional state in pollock and larger seasonal and interannual variations in this indicator (Fig. 1.4). The cold intermediate layer (CIL) maintains the water temperature below 0 °C for very long periods in these two regions, thus, hampering development of the feeding zooplankton. The CIL dissipation depends on intensity of the warm Pacific water influx into the Bering Sea in a particular year (Khen, 1988); this process determine peculiarities of the development of the pollock food.

Poor nutritional state in the Navarin pollock is a sign of food deficiency which is the inevitable result of increase in density of the species concentrations. High density of aggregations develops due to favorable conditions for survival of embryos, larvae, and yearlings in stable eddies of the Navarin region and Anadyr Gulf. Worse feeding conditions in the northern part of the

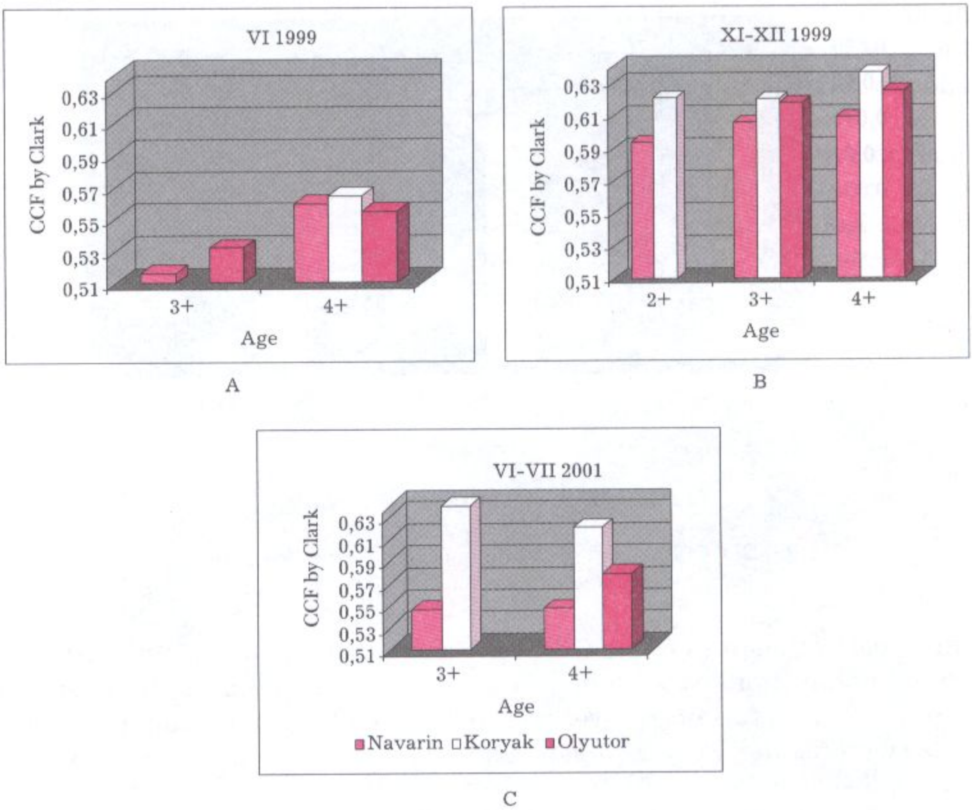


**Fig. 5.3.** CCF by Clark in Northwest Bering Sea pollock, by area and age

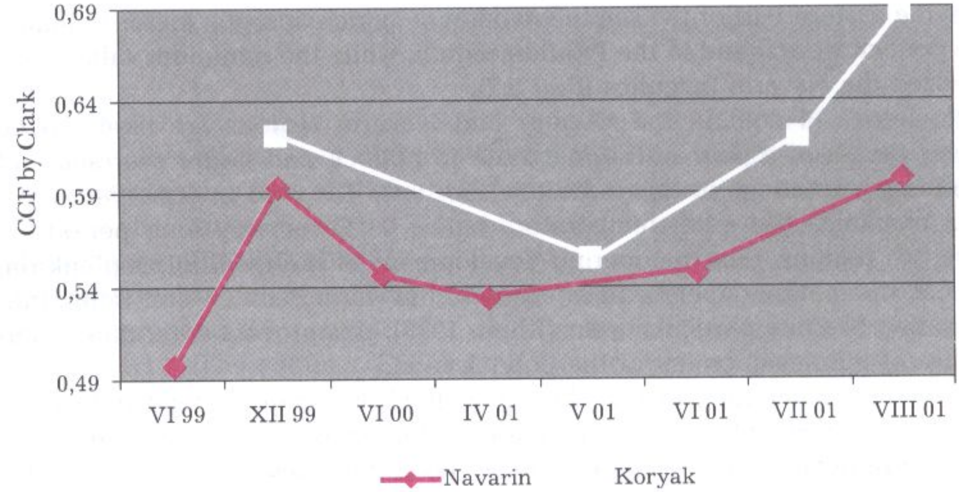


**Fig. 5.4.** CCF by Clark in 1997 year-class pollock in Navarin and Koryak areas

sea, compared to the Koryak region and the eastern shelf, indicate that there are no prerequisites for pollock migrations to the Navarin region from other parts of the Bering Sea.

Consequently, at all stages of the Bering Sea pollock life cycle its nutritional state depends on habitat conditions in a particular region. Interregional differntiations in habitat conditions have a greater impact on the pollock nutritional state than interannual ones.

### Gonadosomatic index

Reproduction is one of the essential function of a population. Time and intensity of reproduction depend on characteristics of a particular biotope (Chapter 3). Adaptive changes in the reproduction process of individual aggregations and populations are reflected in seasonal and interannual dynamics of the relative gonad weight. International symposium on biology and management of walleye pollock, (Anchorage, 1988) agreed that gonadosomatic index (GSI) is an extremely important tool in population studies (Haldorson, 1989; Sakurai, 1989).

Virtually quality and number of mature oocytes (GSI as a proxy), determine the population fecundity and subsequent survival on embryos. On the other hand, these features reflect habitat conditions of the population. So the GSI dynamics in mature females is one of the most important index for the population analysis.

The GSI value for mature female pollock showed more similarity between the Koryak and Olyutor regions than between these two regions and the Navarin region (Fig. 5.5).

On the interannual scale, regional variations in the pollock GSI showed an opposite sign. Thus, in November-December, 1998, the relative gonad weight of the Navarin female pollock (3.28%) was less, than that of female pollock from the Koryak and Olyutor regions (3.61% in both the regions); while in November – December, 1999, on the contrary, this indicator for the Navarin pollock had the maximum value (3.85%) for the entire period of our surveys (Fig. 5.5). High productivity levels which the Navarin female pollock achieved by winter 1999-2000 were *inter alia* a prerequisite of emergence of the strongest year-class in the last decade (the 2000 generation) (Chapter 3). The Navarin pollock generation of 1999 was 3.28 times less abundant than that of 2000. It is noteworthy that by the end of the feeding period in the previous year the Navarin pollock GSI was the worst of all three surveyed regional aggregations (Fig. 5.5).

Gonadosomatic indices in male pollock from the Navarin, Koryak, and Olyutor regions did not differ so much as in females in 1998 – 2001 (Fig. 5.6). However, the index dynamics was regionally specified.

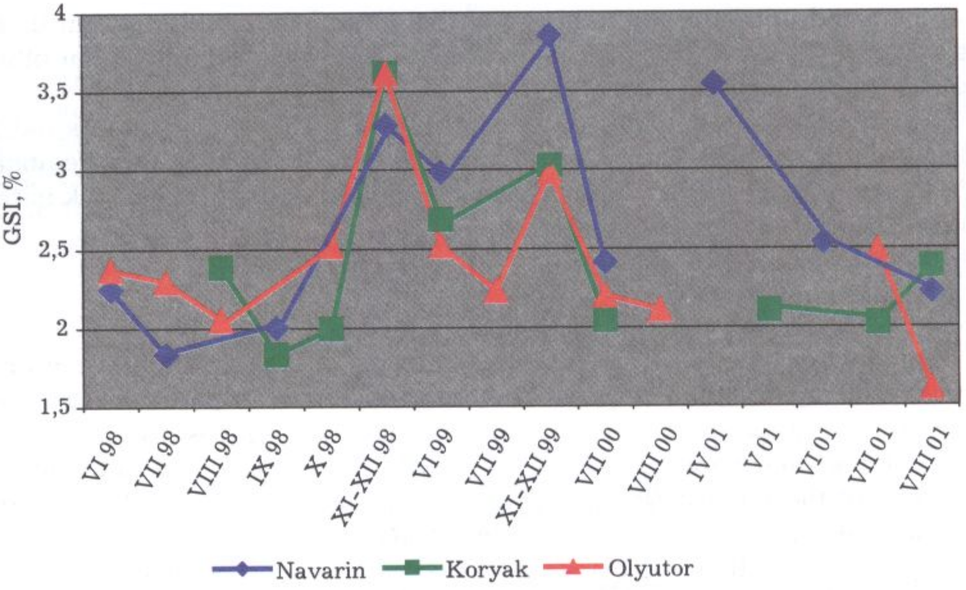


**Fig. 5.5.** Gonadosomatic index in mature female pollock of the Northwest Bering Sea, by area

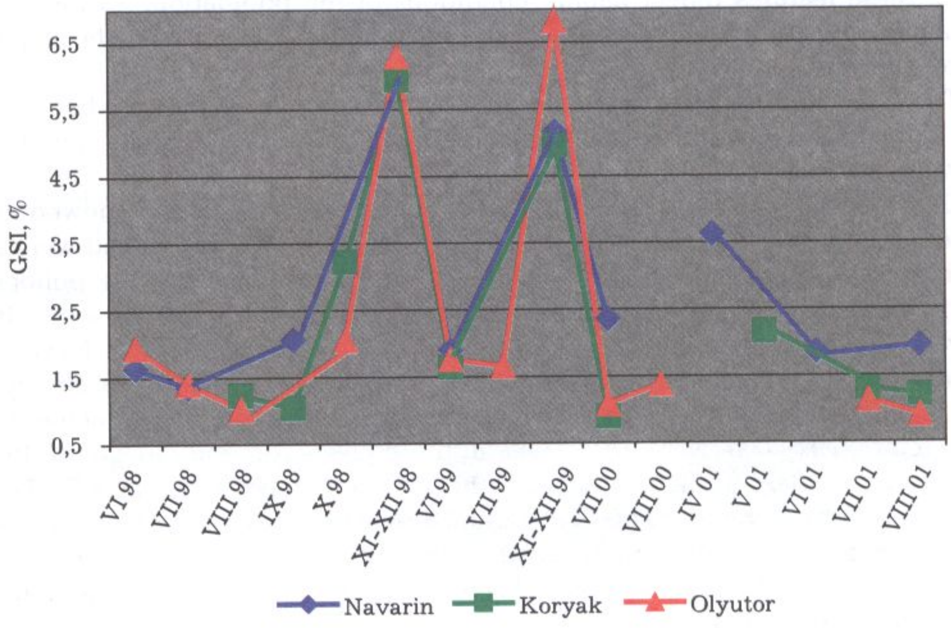


**Fig. 5.6.** Gonadosomatic index in mature male pollock of the Northwest Bering Sea, by area

Comparison of the pollock gonadogenesis in the Bering Sea regions with different spawning time revealed the following. Our surveys showed that there was a statistically significant advance in the seasonal gonadogenesis in pollock from Kronotskiy Bay compared to it northern neighbors. In October-November, 2003, the Kronotskiy Bay pollock GSI made 7.36% in females and 9.55% in males, while in the Navarin region this index was 4.22% and 5.02%, respectively (Fig. 5.7). This difference was noticed even in 4+ individuals, though part of this age group had not yet reached sex maturity (Appendices 1.2 and 1.3).

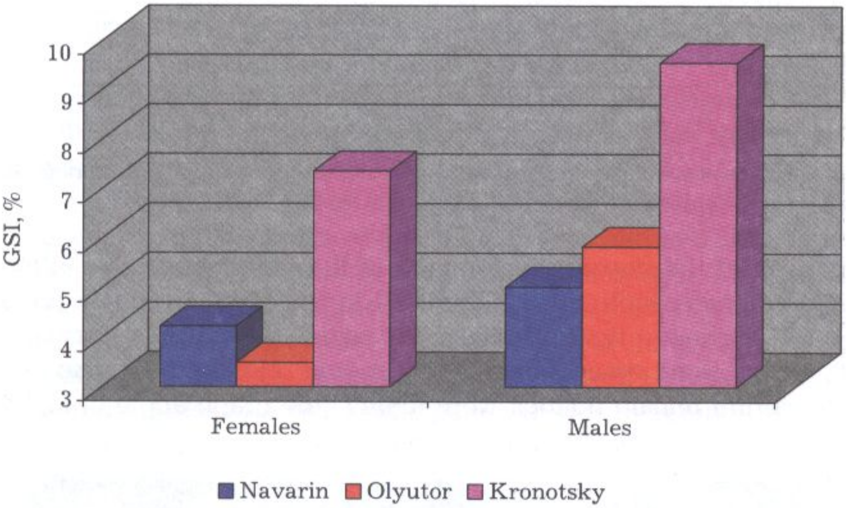
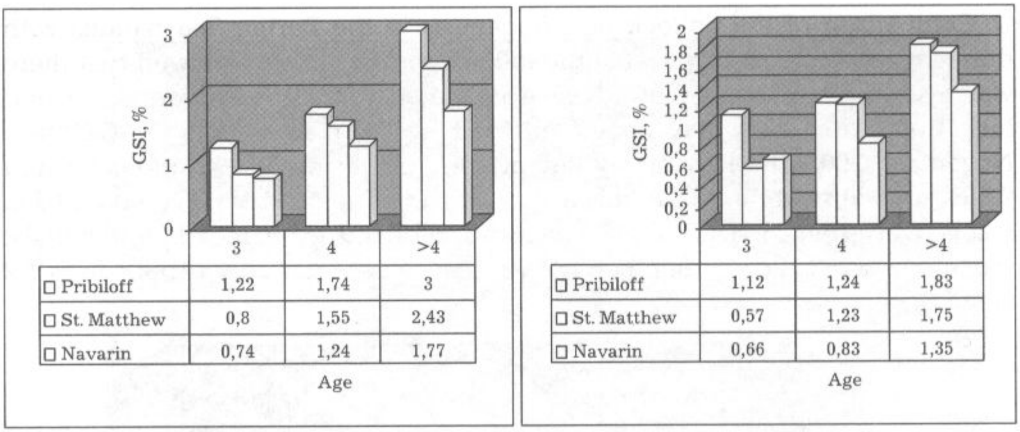


**Fig. 5.7.** Gonadosomatic index in mature pollock in northern and western regions of the North Pacific in October–November 2003

Authores' data in the Northeast Bering Sea (July 2004) indicated that in the warmer Pribiloff region GSI was higher than in colder waters of the St.Matthew region and much higher than in the northernmost Navarin region (Fig. 5.8). The GSI differntiations in females of the Pribiloff and Navarin pollock were statistically significant.

The advanced maturing of gonads in pollock of the Kronotskiy Bay, coastal waters of East Kamchatka, and in Pribiloff region is associated with earlier spawning in these regions, compared to Olyutor, Karagin Bays, or the Navarin region (Fadeev, 1991; Shuntov et al., 1993; Stepanenko, 2003). Such adaptation of gonadogenesis would only develop if pollock shoals remained within their respective regions and did not make long migrations. Hence if peculiarities of gonadogenesis were less prominent in a particular region, this would indirectly indicate long migrations of pollock from such region and/or a considerable inflow of migrants.



A

| | 3 | 4 | >4 |
|---|---|---|---|
| ☐ Pribiloff | 1,22 | 1,74 | 3 |
| ☐ St. Matthew | 0,8 | 1,55 | 2,43 |
| ☐ Navarin | 0,74 | 1,24 | 1,77 |

B

| | 3 | 4 | >4 |
|---|---|---|---|
| ☐ Pribiloff | 1,12 | 1,24 | 1,83 |
| ☐ St. Matthew | 0,57 | 1,23 | 1,75 |
| ☐ Navarin | 0,66 | 0,83 | 1,35 |

**Fig. 5.8.** Gonadosomatic index in females (*A*) and males (*B*) of pollock from various areas of the North and East Bering Sea, by age (July 2004)

Comparison of the gonad development at the ontogenesis also allowed us to identify regional peculiarities. Thus, GSI in the Navarin female pollock at age 2+ −3+ exceeded that in females the same age from the Koryak region (Fig. 5.9). At the same time in the Koryak region rates of the gonad development in immature female pollock were higher (the graph angle of inclination

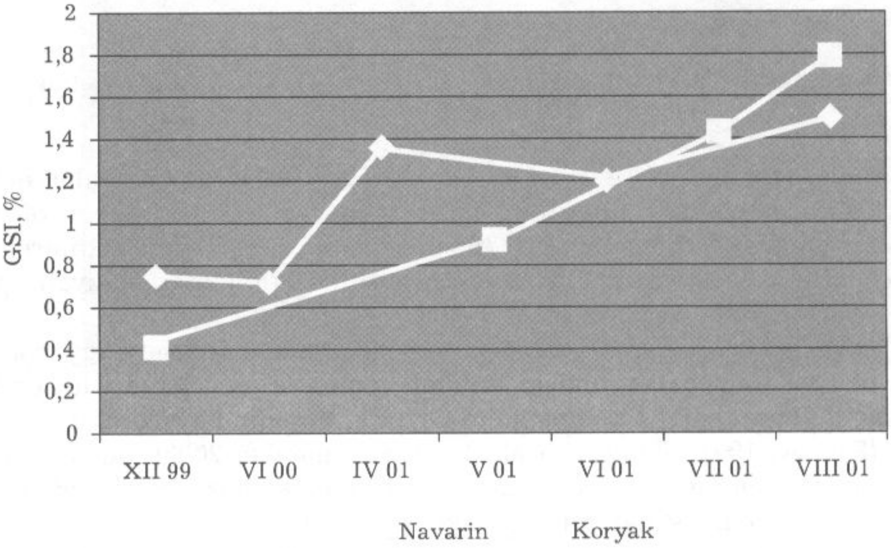


**Fig. 5.9.** Gonadosomatic index in the 1997 year-class of female pollock in Navarin and Koryak areas

is bigger) than those in the Navarin region. As a result, GSI of female pollock at age 3+ in the Koryak region become higher than that in the Navarin region. This could be related to a quicker maturation of pollock in relatively warm waters of the Koryak region compared to the Navarin region. As it was already mentioned in Section «Cubic condition factor», another cause of a quicker gonad development in the Koryak pollock could be better feeding conditions in absence of very dense concentrations of fish.

Climate/oceanic peculiarities determine not only interregional variations but also specifics of gonadogenesis in particular years. Thus, in December 1999, and in June 2000, GSI in the Navarin male pollock was higher than in the same seasons in 2001, 2003, and 2004. As it was shown above, in the surveyed period of 1998-2001, the maximum value of GSI in mature females of the Navarin pollock were registered in November – December 1999 (Fig. 5.4). In June 2000, GSI in 2+ females was four times higher than that recorded during summer surveys of 2001 and 2004.

Increase in the relative gonad size was probably associated with favorable climate/oceanic characteristics of a particular year and low abundance of the Bering Sea pollock at the turn of the century. Large size of gonads during prewintering period indicated good readiness of pollock for the next spawning, while a higher value of GSI in June meant a longer spawning of the Navarin pollock in 2000. Large size of ovaries in the 2+ female pollock could be considered a proof of active participation of this generation in the spawning of 2000. All this could contribute to emergence of an high abundant year-class of the Navarin pollock in 2000. It is noteworthy that in July 2000, pollock in Olyutor Bay and waters of the Koryak Plateau had GSI even lower than in other surveyed years (1998 – 2004). This shows peculiarity in the pollock functioning in each of these regions. The year 2000 was favorable for reproduction (maturation) of the Navarin pollock only.

The minimum interannual value of GSI in the Navarin pollock of both sexes were recorded at the onset of the feeding periods in 1998 (1.83% and 1.33% females/males respectively) and in 2004 (1.77 and 1.35%). According to data of juvenile surveys, the 1998 year-class was weak and its abundance was 9.4 times smaller than that of the 2000 year-class. According to preliminary data, the 2004 generation also has smaller abundance that the mean long-term one. The observed by us small relative weight of gonads already in June – July allowed us to conclude that spawning in the Navarin region was not successful in those years (1998, 2004).

Indices of the organ (especially GSI as one of the most labile indices) indirectly help us assess the pollock shoals genesis from one or another one region. When pollock of various genesis each of which has specific morphophysiological adaptations occurs in a region jointly, sampling from this region will include individuals which represent several groups by values of the studied characteristics. Presence of several groups in a sampling leads to increase in the coefficient of variation (CV). Therefore, we analyzed values of coefficients of variation for gonadosomatic and hepatosomatic indices (HSI) in female pollock from the Navarin region and Olyutor Bay in order to determine the degree of homogeneity in the former region. Absence of migrants in Olyutor Bay (Balykin, Maksimenko, 1990; Fadeev, 1991; Shuntov et al., 1993) allows us to use this sample as a reference for homogeneous pollock shoals.

Analysis of values of the coefficients of variation (CV) for the GSI and HSI in female pollock from samples (not less than 100 ind.) revealed that there were no significant variations between the Navarin and Olyutor pollock in the same periods of the annual cycle: the maximum values exceeded 8%, while the minimum ones made 2–3% in both regions (Table 5.1).

**Table 5.1.** Coefficients of variations (CV) in gonado- and hepatosomatic indices in female pollock, by area, year and month (%)

| Year | Month | Navarin region | | Olyutor Bay | |
|---|---|---|---|---|---|
| | | GSI | HSI | GSI | HSI |
| 1998 | VI | | | 8.02 | 1.42 |
| | VII | 3.28 | 2.78 | | |
| | VIII | | | 3.90 | 1.34 |
| | X | | | 2.38 | 1.73 |
| | XI–XII | | | 3.60 | 1.53 |
| 1999 | VI | 8.72 | 3.12 | 6.75 | 2.36 |
| 2000 | VII | 5.39 | 2.29 | 4.55 | 3.16 |
| | VIII | | | 5.21 | 1.57 |
| 2001 | VI | 4.74 | 1.95 | | |
| 2002 | IV | | | 5.24 | 2.15 |
| 2003 | X–XI | 4.27 | 1.93 | | |

*Note:* the sample size was ≥ 100 ind.

Similarity of the CVs suggests homogeneity of the Navarin pollock shoals during the surveyed period. Interregional differentiations in CVs of the GSI in June 1999 and July 2000 explained by an earlier end of spawning in Olyutor Bay. By June-July, the majority of females from Olyutor Bay had small-sized gonads characteristic of the postspawning period, while in the Navarin region there were individual females with large-sized gonads at the IV stage of maturity and other part of Navarin females had postspawning small-sized gonads which explained a higher CV of GSI for Navarin females (4.55–6.75% and 5.39–8.72% in Olyutor Bay and the Navarin region, respectively) (Table 5.1).

If the Navarin region had accommodated pollock from the eastern part of the sea where spawning finished earlier than in Olyutor Bay, we would have seen the opposite: the GSI CV would have been lower in the Navarin region. This is another evidence that pollock captured in the Navarin region in feeding period had its spawning in the very same region.

## Hepatosomatic index

Dwelling in the most severe conditions, the Navarin pollock has a short feeding period and it, as a rule, determine the minimum value of hepatosomatic index (Fig. 5.10, 5.11). Variations between regions are statistically significant (Table 5.2).

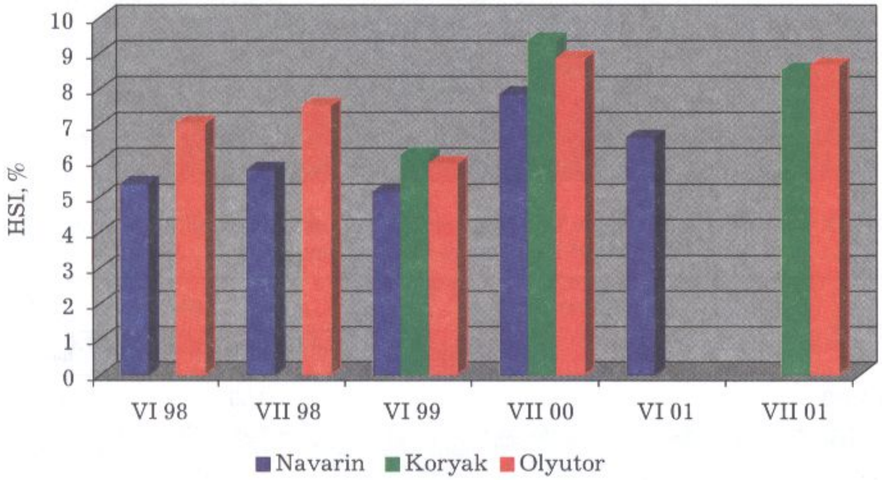


**Fig. 5.10.** Hepatosomatic index in mature female pollock in the early feeding period in the Northwest Bering Sea, by area

November—December of 1998 was exception for mature pollock of both sexes when the HSI value in the Navarin pollock was higher than in the Koryak and Olyutor pollock. It is known that the year of 1998 was anomalously warm in the Navarin region (Borets et al., 2002). It is likely that a longer feeding period and at the same time higher rates of energy accumulation intrinsic to northern inhabitants allowed the Navarin pollock to accumulate more energy resources in its liver which explains increase in its relative size.

Seasonal interregional diversity in HSI in mature pollock also depend on the period of the annual cycle when the measurements were taken. Obviously, simultaneous measurements taken in regions with different climate/oceanic conditions would coincide with different periods of the annual cycle.

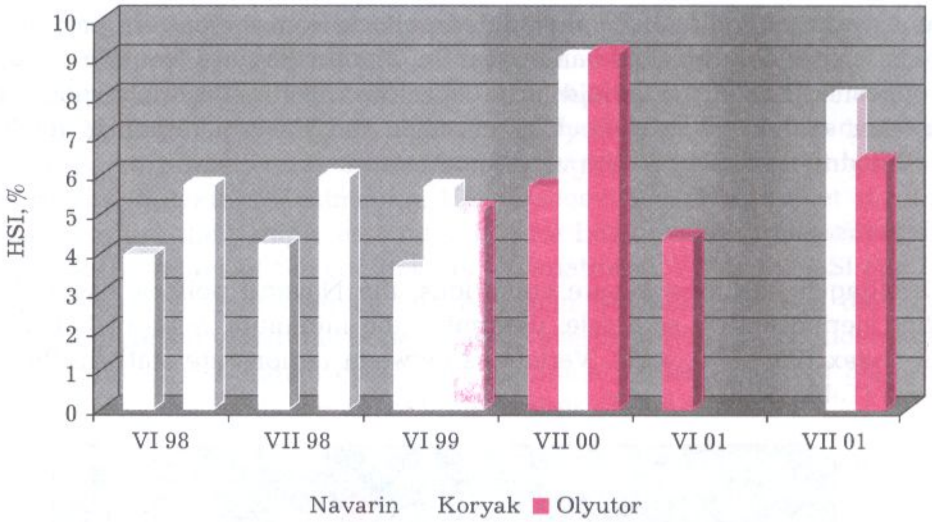


**Fig. 5.11.** Hepatosomatic index in mature male pollock in the early feeding period in the Northwest Bering Sea, by area

**Table 5.2.** Student criterion value in hepatosomatic indices in Navarin pollock compared with that of Koryak and Olyutor Bay pollock

| Period | Koryak region | | Olyutor Bay | |
|---|---|---|---|---|
| | females | males | females | males |
| VI 1998 | | | 3.60 | 4.01 |
| VII 1998 | | | 5.87 | 4.64 |
| VI 1999 | 4.64 | 5.18 | 3.76 | 4.72 |
| VII 2000 | 5.58 | 7.96 | 3.03 | 5.26 |
| VI – VII 2001 | 7.82 | 12.86 | 7.21 | 5.63 |

In April 2002, in the peak of spawning in Olyutor Bay HSI in female pollock made 6.99 %, while in waters of the Koryak plateau where spawning had not yet started, HSI in females was 8.22% (Annex 1.4). Because of a lower intensity of the generative metabolism in males, their differntiations in HSI were smaller: 5.57 and 5.97%, respectively (Annex 1.5). In November 2003, hepatosomatic index in the Olyutor Bay pollock (7.75% and 7.16% in females and males, respectively) was lower that in the East Kamchatka pollock (10.49 and 8.94%) with the earlier spawning (Annex 1.4, 1.5).

Compared to the southern pollock individuals, the smaller relative size of the Navarin pollock liver at the onset of the feeding period indicated also that at this region spawning finished later and liver would not be able to accumulate surplus nutrient substances by June—July (Glubokov, Kotenev, 1999; Glubokov et al., 2002).

Northern immature pollock also had a lower HSI compared to its southern neighbors, e.g. comparison of pollock from the Navarin and Koryak regions (Fig. 5.12, 5.13).

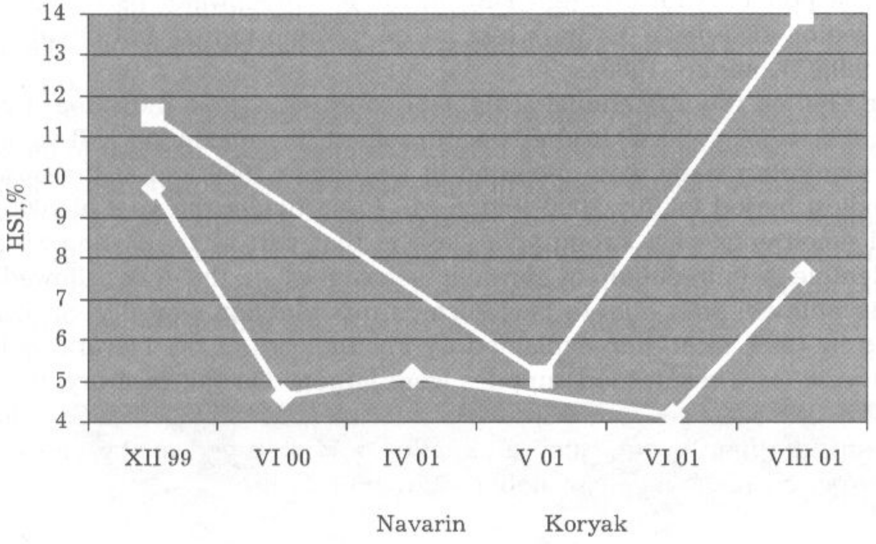


**Fig. 5.12.** Hepatosomatic index in female pollock of the 1997 year-class in Navarin and Koryak areas

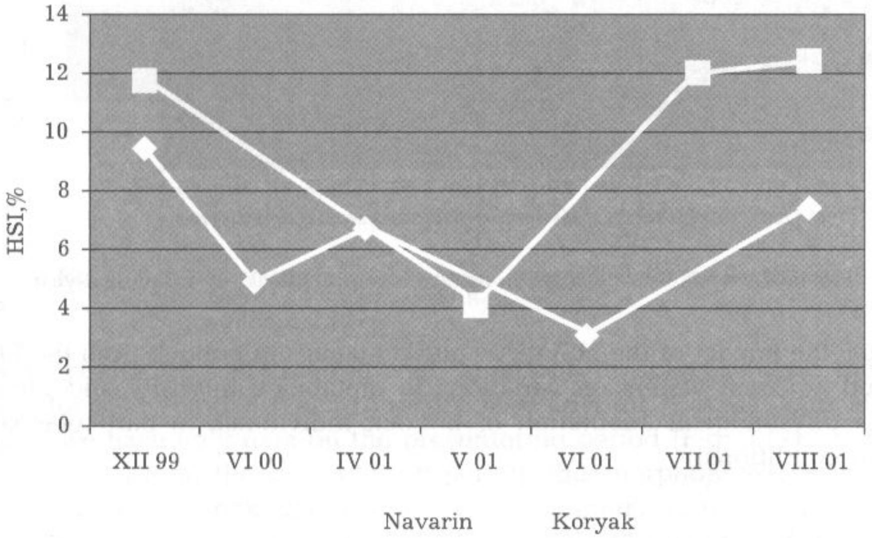


**Fig. 5.13.** Hepatosomatic index in male pollock of the 1997 year-class in Navarin and Koryak areas

Thus, in the Navarin region, the 1997 pollock generation at age 2+ –4+ (both females and males) had a lower HSI value than in Koryak region.

Differences in the pollock HSI values were also noticed between shelf and deepwater areas of the Bering Sea. Data collected during two trawl surveys in the Southwest Bering Sea (September – October 1987), allowed to identify two groups of pollock with different HSI. In the east deepwater part of the surveyed region HSI made 12.3%, while in the Karagin region and Olyutor Bay it was 9.9% (Kotenko, 1988).

Like GSI, on the interannual scale, HSI could be a good indicator of physiological state of pollock. In the Navarin region, the maximum HSI values at the prewintering stage were recorded in December 1999 and at the onset of the feeding period in July 2000 (Fig. 5.14). In particular the year of 2000 witnessed emergence of a strong year-class in that part of the Bering Sea, i.e. considerable accumulation of nutrient substances in the liver allowed the Navarin pollock, *inter alia*, to maximize its reproduction capacity. Successful feeding in 1999, *inter alia*, explained by low biomass of the Navarin pollock in that year (as a result food supplies were larger). On the contrary, in years of the biomass increase food competition worsened feeding conditions and the HSI value dropped down. Such a situation was observed at the end of the feeding period (October – November) 2003 (Fig. 5.13).

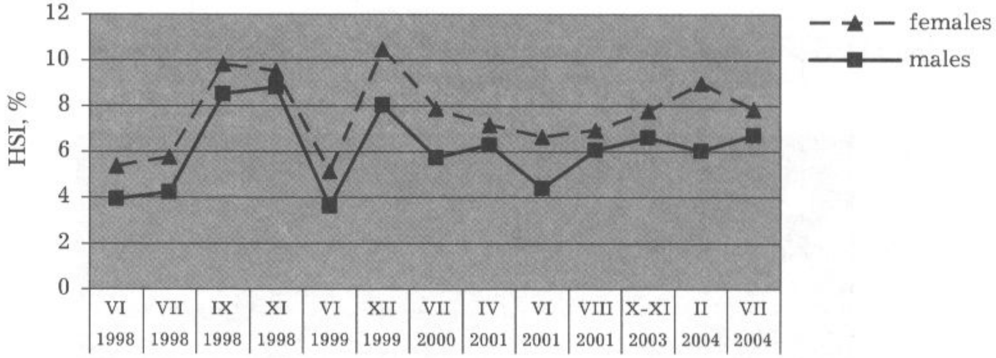


**Fig. 5.14.** Hepatosomatic index in mature Navarin pollock, by month and year

Thus, the impact of the HSI value and dynamics in pollock from the Bering Sea and adjacent waters on variations in metaboloc intensity and direction reflects physiological adaptation of pollock individuals to particular statios (habitat conditions).

**Spleensomatic index**

Seasonal and interannual dynamics of spleensomatic index (SSI) in the Northwest Bering Sea pollock is most particular in Olyutor Bay. It is noteworthy that values of GSI and HSI distinguished pollock shoals in the Navarin region from those in the Olyutor and Koryak regions, while in case of SSI, it was the Olyutor pollock that stood out against the other stocks (Fig. 5.15, 5.16, Annex 1.6, 1.7).

The SSI value in Olyutor pollock demonstrated rapid changes not only on the scale of the year cycle periods, but also within such periods. Thus, during the feeding period of 2000, the SSI value in mature female pollock increased from 0.169% (July) up to 0.205% (August). The range of the SSI variations in the Olyutor male pollock was even greater: during the very same period of 2000, SSI in males increased from 0.164% up to 0.217%. The variation range of SSI values in the Navarin and Koryak pollock is shorter (Fig. 5.14, 5.15).

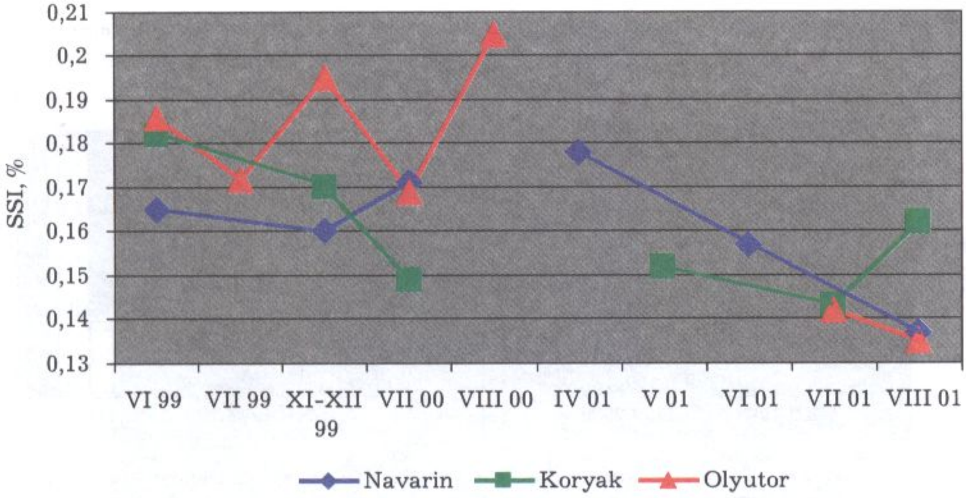


**Fig. 5.15.** Spleensomatic index in mature female pollock in the Northwest Bering Sea, by area

As to comparison of interregional variations in spleensomatic index in pollock for four regions (i.e. Kronotsky bay, Olyutor, Koryak, and Navarin regions), we have only data on the prewintering period (Fig. 5.17).

As a rule, during the prewintering period, this morphophysiological indicator in mature pollock demonstrated the minimum value in the Navarin region (Fig. 5.14, 5.15, 5.16). Maximum values of SSI were found in the East Kamchatka pollock (Kronotsky bay).

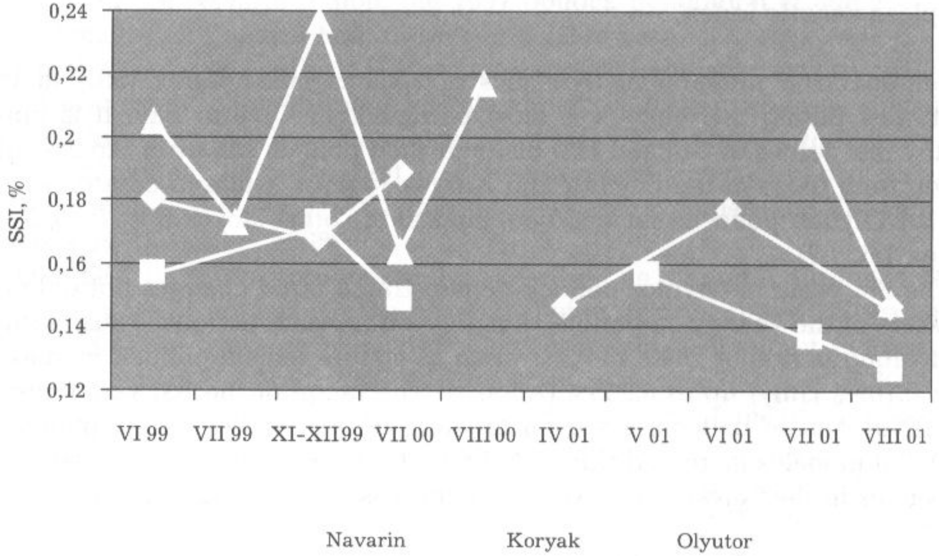
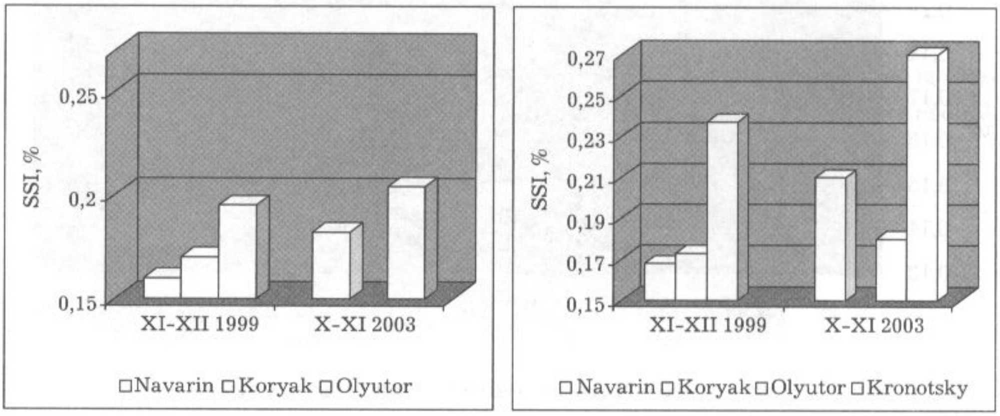


**Fig. 5.16.** Spleensomatic index in mature male pollock in the Northwest Bering Sea, by area



A

B

**Fig. 5.17.** Spleensomatic index in mature female (*A*) and male (*B*) pollock in prewintering period, by area

The largest relative weights of spleen in immature pollock from the Northwest, North, and East Bering Sea characterized the Navarin and St.Matthew pollock (Fig. 5.18 – 5.21).

Thus, first study of the SSI dynamics for pollock made by us revealed distinctive regional (population) peculiarities of the index, which could be of adaptive nature.

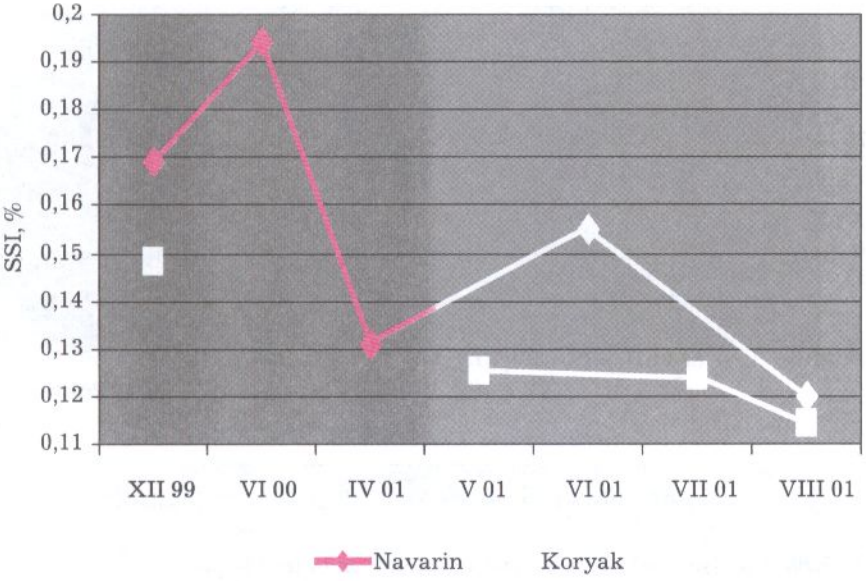


**Fig. 5.18.** Spleensomatic index in female pollock of the 1997 year-class in Navarin and Koryak areas

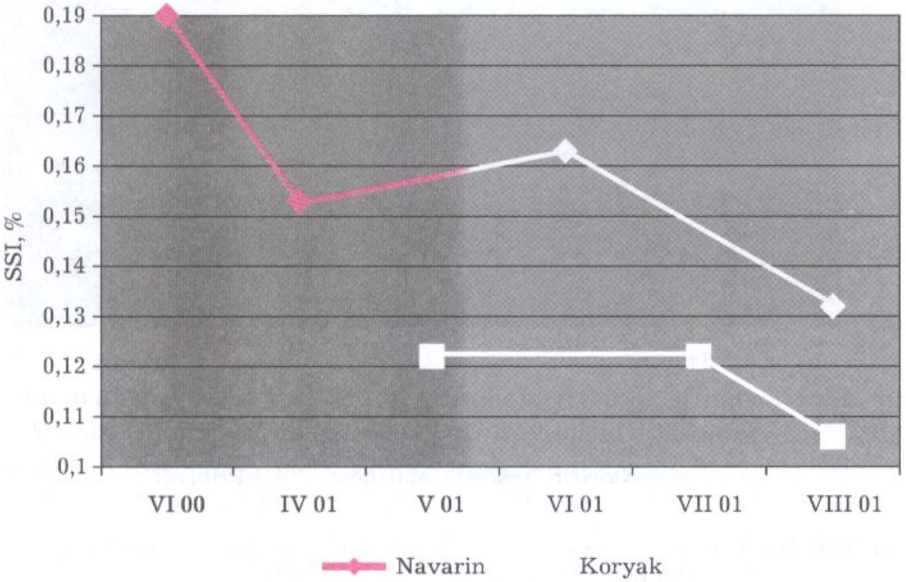


**Fig. 5.19.** Spleensomatic index in male pollock of the 1997 year-class in Navarin and Koryak areas

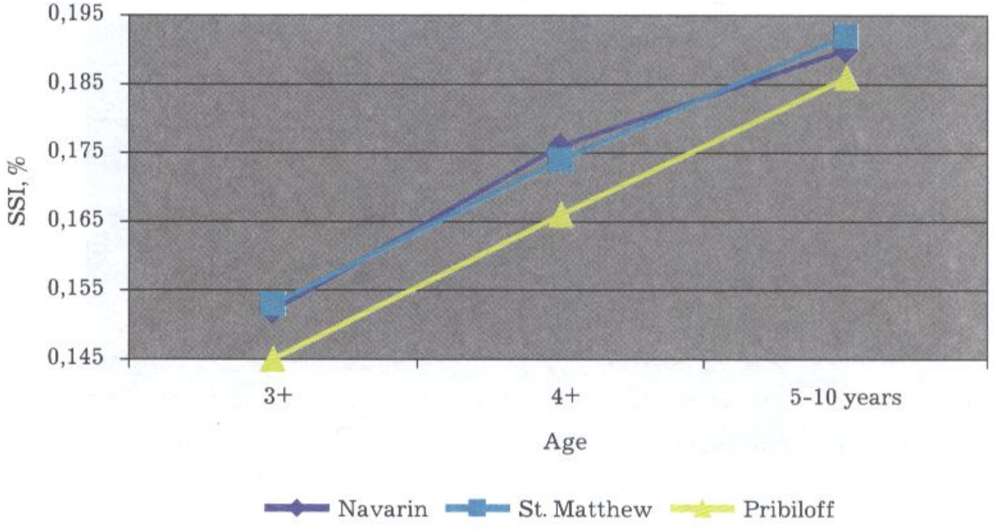


**Fig. 5.20.** Age dynamics of the spleensomatic index in female pollock in the North and East Bering Sea by area in July 2004

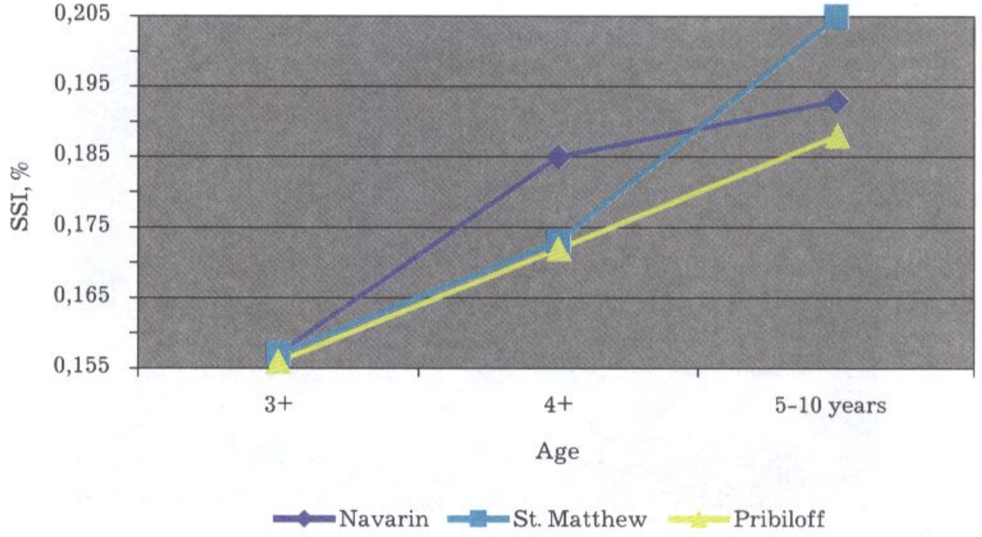


**Fig. 5.21.** Age dynamics of the spleensomatic index in male pollock in the North and East Bering Sea by area in July 2004

## Cardiosomatic index

Interregional differences in cardiosomatic index (CSI) in pollock from the Northwest, North, and Northeast Bering Sea are less regular than those in GSI, HSI, and SSI. However, dynamics of CSI in the Koryak, Navarin, St.Matthew, and Pribiloff pollock are very particular. As a rule, CSI in mature pollock from the Navarin region is higher than in its southwest neighbors (the Koryak pollock), and lower than in fish from the southeast (the St.Matthew and Pribiloff regions) (Fig. 5.22 – 5.25).

Juveniles demonstrated a reverse tendency: in similar periods, CSI in the Navarin pollock was lower than in the Koryak one; this is well illustrated by the case of the 1997 generation (Fig. 5.26, 5.27).

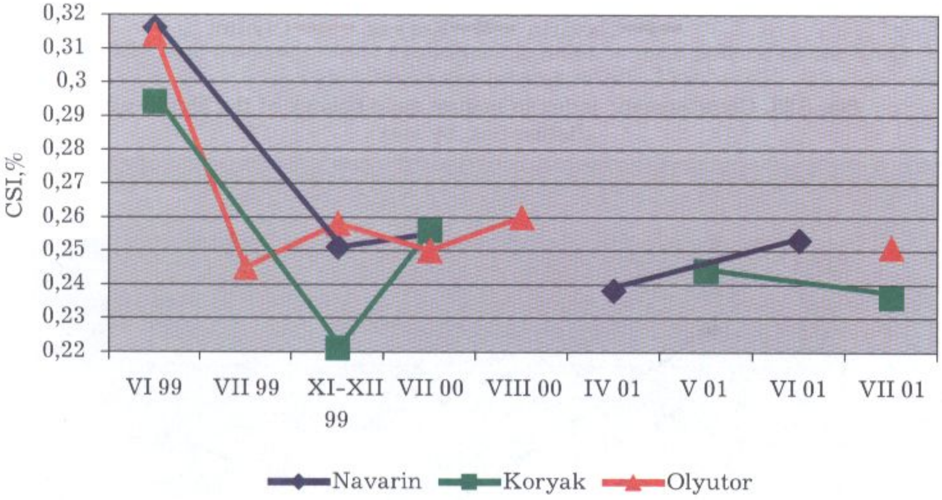


**Fig. 5.22.** Cardiosomatic index in mature female pollock of the Northwest Bering Sea, by area

Summarizing the discussion of morphophysiological indicators in pollock, we should highlight the following. Biological differences in the East Kamchatka (Kronotsky bay), West Bering Sea (Olyutor Bay), Navarin, and the East Bering Sea (St.Matthew and Pribiloff) pollock caused development of morphophysiological adaptations to particular statios. The essential condition of appearance of such adaptations is a certain degree of isolation of shoals from each other which was shown in Chapter 1.

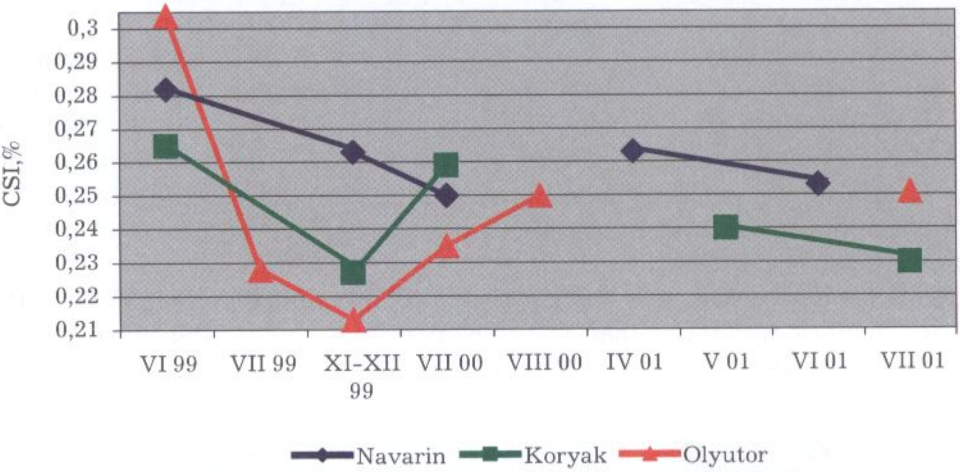


**Fig. 5.23.** Cardiosomatic index in mature male pollock of the Northwest Bering Sea, by area

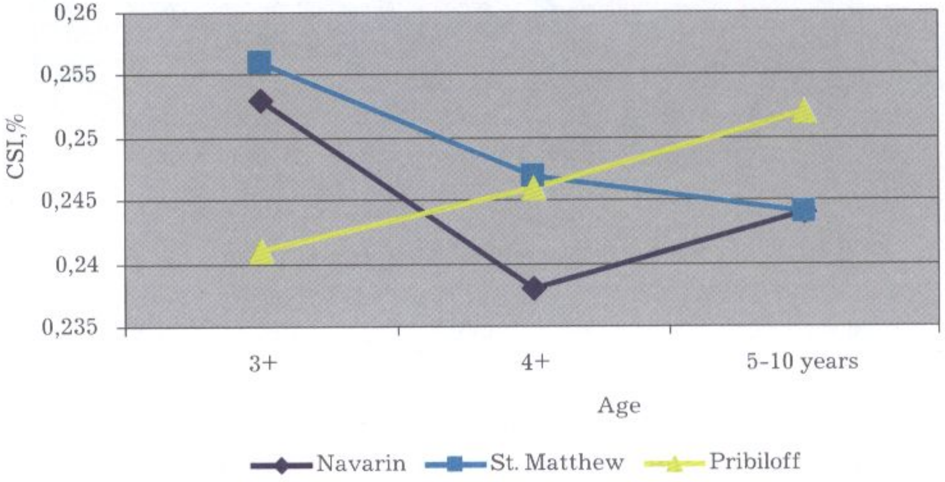


**Fig. 5.24.** Age dynamics of the cardiosomatic index in female pollock of the North and East Bering Sea by area in July 2004

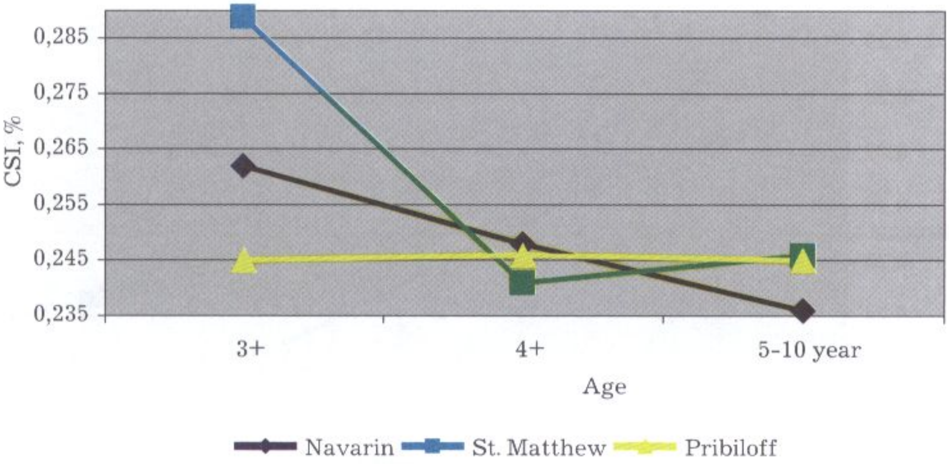


**Fig. 5.25.** Age dynamics of the cardiosomatic index in male pollock of the North and East Bering Sea by area in July 2004

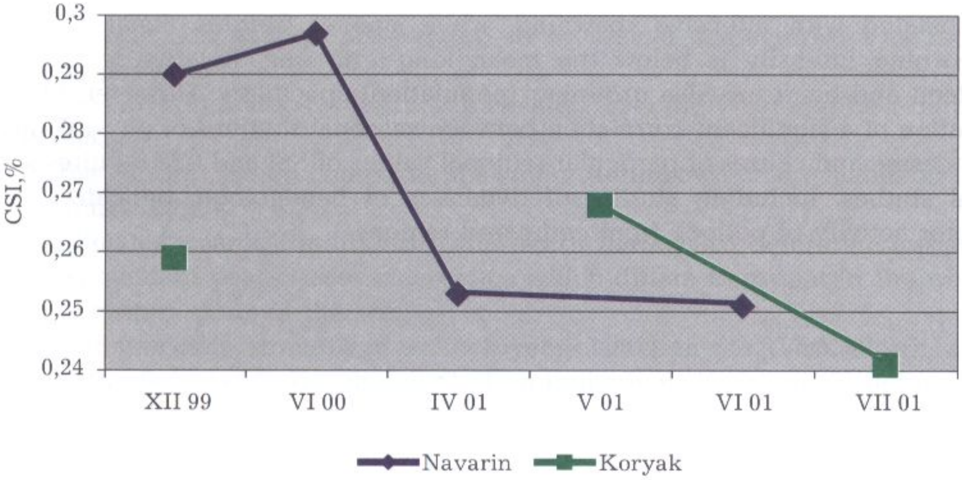


**Fig. 5.26.** Cardiosomatic index in female pollock of the 1997 year-class in Navarin and Koryak areas of the Bering Sea

Rates of gonadogenesis in the North Bering Sea pollock are lower than those in the southern stocks. Seasonal dynamics of the HSI is region specificity. In cold northern regions with a short feeding period, HSI and cubic condition factor were lower than in the southern waters. Values of GSI and HSI are indicators of metabolic processes both on the individual, and on the groupings levels and reflect the feeding success and expected intensity of spawning in a particular region. Large relative weights of gonads and liver are

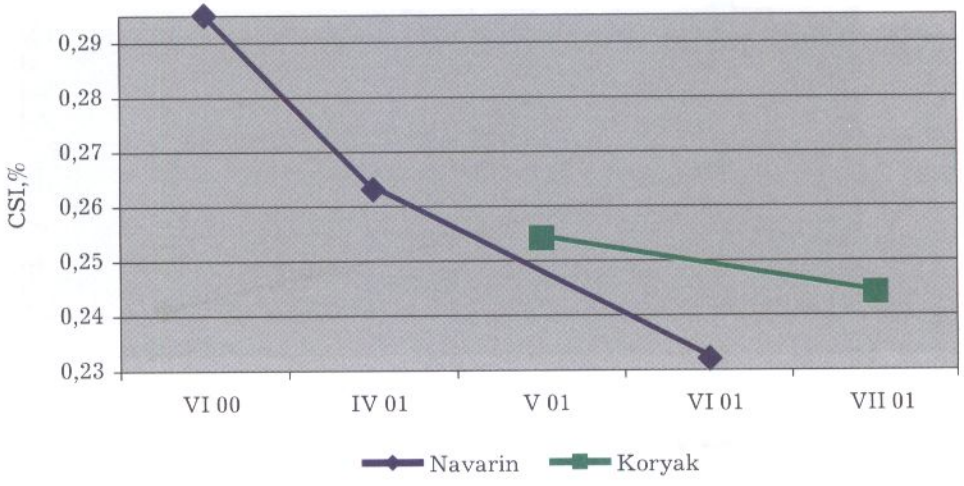


**Fig. 5.27.** Cardiosomatic index in male pollock of the 1997 year-class in Navarin and Koryak areas of the Bering Sea

associated with intensive spawning, while smaller weights mean that the spawning intensity is below the mean long-term one. Relative weights of spleen and heart are also grouping (population) specificity. However, identification of a significant correlation between seasonal rhythms of physiological processes and causes of particular regional values of SSI and CSI requires special studies, including studies of dynamics of hematologic indicators and motor activity of pollock from compared regions.

# CHAPTER 6

## STOCK STRUCTURE OF THE NORTH BERING SEA POLLOCK

In previous chapters we analyzed biological observations of the North Bering Sea pollock obtained with our original science technique and compared with numerous published literature data. It was established that the North Bering Sea pollock possess the all biological characteristics of independent population:

- the Navarin pollock is fairly well isolated from the West and East Bering Sea stocks;
- the Navarin region comprises spawning grounds which are stable on the interannual scale;
- climate/oceanic conditions of the North Bering Sea determine the pattern of abundant year-classes emergence which differs from that in the western and eastern parts of the sea;
- differences in strength of pollock year-classes in the West, North, and East Bering Sea lead to development of an individual size-at-age structure for each regional pollock grouping.

However, we could not be completely confident that the North Bering Sea inhabits an independent pollock population if no unique environmental conditions necessary to maintain a relative seclusion of stocks had developed in this region reasonably long ago. It is well-known that in the 1980s, the Bering Sea pollock abundance attained it maximum, which led to mergence of majority of previously separate shoals. If such a mergence had repeated fairly often during the previous historical period, no independent pollock population with its specific adaptations could have been formed. The fact that pollock in the Navarin region has developed morphophysiological adaptations to the North Bering Sea environment and variations of the morphological characteristics different from those in other regions (Serobaba, 1977; Hashimoto, Koyachi, 1977; Koyachi, Hashimoto, 1977; Glubokov, Kotenev, 1999; Glubokov et al., 2002; Kim, Yang, 2002; Nishimura, 2002) indicates that this region has been a site of formation of relatively secluded stocks very long.

On the modern level of knowledge the final stage of population identification studies is analysis of the genetic structure of groupings. In complex with biological studies, identification of genetic markers help once and for all confirm that there is no significant genetic drift between the surveyed shoals.

The following section is devoted to analysis of collected and published data on the Bering Sea pollock genetic structure.

## Genetic structure

The principal methodological approach to population genetics is identification of statics and dynamics of allele frequencies and the genotype composition in natural concentrations of a special rank (Yablokov, 1987). The assessment precision depends on several factors: the sampling size, location and time of the genetic specimen collection, and the level of markers polymorphism. Sampling of species with a high level of genetic drift such as pollock, should consist of minimum 50 individuals (Olsen et al., 2002), besides it should be made exactly during the spawning period (Bailey et al., 1999 b; Glubokov et al., 2002).

**Protein polymorphism.** Variability in genes or DNA fragments could be indirectly assessed through the protein analysis. Unfortunately, this technique implies double possibility of loss/distortion of information: at transcription (read-out of the genetic information from DNA molecules to RNA molecules) and translation (read-out of the genetic information from RNA molecules to proteins). As a technique of the population structure assessment, electrophoresis of proteins is more appropriate for analysis of freshwater and anadromous fish species with a low genetic drift. In sea-fish, genetic drift hampers population differentiation. However, at early stages of population-genetics studies, when the direct analysis of DNA structure was a technically difficult task, the most popular technique was analysis of allozyms as genetic markers. With time geneticists started to use this method as a supplement to direct assessment of nucleotide sequences in most rapidly evolving DNA loci.

Studies of the protein polymorphism revealed that the Bering Sea pollock genotype varies, depending on the spawning ground (Flusova, Moiseev, 1981). At the same time some studies failed to differentiate pollock stocks by protein markers (Johnson, 1977).

Earlier studies of the pollock superoxide dismutase (SOD) showed that there was a latitudinal variability in alleles from the southwest to the northeast (Iwata, 1975, Yanagimoto, 2002). Later the Alaskan geneticists failed to differentiate pollock from different geographical regions by allozyms (except SOD: the allele frequencies varied in pollock from the East Bering Sea, Gulf of Alaska, and Kronotsky Bay. At that in 1998, this difference was clearer than in 1997. The Americans suggested that the pollock SOD alleles were affected by the directed selection, and this fact allowed researchers to apply this locus in their population-genetic studies (Seeb et al., 2002).

In the 1970s, researchers from the NorthWest and Alaska Science Center made electrophoresis of 28 loci responsible for synthesis of tissue enzymes in spawning pollock from waters off the Pribiloff Islands, the South East Bering Sea, and Gulf of Alaska. Eight loci were polymorphic and only two of them (malone enzyme-2 and 6-phosphogluconate dehydrogenase) were characterized by a heterozygosity level sufficient for genetic analysis of pollock populations. Highly polymorphic SOD (found earlier by Iwata (1975) did not allow American researchers to use this enzyme in their analysis. Its high level of polymorphism could be associated with differences in extraction techniques (Grant, Utter, 1980). Based on the cluster analysis all samples were combined into two large groups: one for the Bering Sea and the other for Gulf of Alaska. No variations in protein polymorphism of the analyzed loci from the Bering Sea were found (Grant, Utter, 1980).

The TINRO geneticists have used the protein biochemical polymorphism in the pollock population studies since 1976. Based on integrated results of studies, particularly, the first identified polymorphism of muscular esterase, blood serum esterase, and blood serum transferine, the geneticists identified seven pollock populations in the Bering Sea: the Karagin-Olyutor, Navarin, St. Matthew, Pribiloff, Unimak, Bristol, and the South Bering Sea ones (Flusova, Bogdanov, 1986; Flusova, 1987).

Studies in the Institute of the Marine Biology revealed polymorphism of muscular phosphoglucomutase, aspartataminotransferase, sorbitoldehydrogenase, isocitratedehydrogenase, malatdehydrogenase, ά-glycerophosphatdehydrogenase, and esterase in pollock samples from the Bering and Okhotsk seas. Predictably, groupings within a sea were less clearly differentiated by these proteins than those from different seas (Mihailova, 1991).

Genetic studies of the Bering Sea pollock sampled from spawning stocks in 1980 – 1990 included analysis of three DNA loci responsible for synthesis of muscular esterase, blood serum esterase, and blood serum transferine (Katugin, 2002). These loci revealed a considerable difference between pollock from the West Bering Sea, Navarin, St. Matthew and Gulf of Alaska pollock. It is noteworthy that variations between the Navarin and the St. Matthew regions were comparable to those between the St. Matthew region and Gulf of Alaska. Serum esterase clearly distinguished the western (Asian) pollock from the eastern (American) one.

In recent years, researchers have paid more attention to a locus of the membrane transport protein pantofisine I (PanI), because it is influenced by directed selection which depends on the water temperature. This marker was first found in Atlantic cod (*Gadus morhua*), and, later in pollock (Canino et al., 2002; Canino, Bentzen, 2004).

Summarizing studies of the Bering Sea pollock allozyms, K.M.Bailey pointed that it is quite difficult to identify of young populations of marine fish species with a high level of genetic drift using this technique (Bailey et al., 1999 b). Meanwhile some very clear differences between the polymorphism levels of allozyms in the West, North, and East Bering Sea pollock were recognized.

**Studies of mitochondrial DNA.** Since the 1980s, population genetics has increasingly applied analysis of sequences in mitochondrial DNA which, compared to proteins, is more informative for identification of fish populations. In the context of population analysis, mitochondrial DNA differs from genome DNA on two aspects. Firstly, the mitochondrial DNA recombinations are limited, hence the structure remains unchanged when passing on from generation to generation, except new mutations. Secondly, mitochondrial DNA only transmits genetic information via maternal side (Avise et al., 1987). Haplotypes of mitochondrial DNA could reflect the degree of genetic drift between populations.

American geneticists studied pollock from the Central Bering Sea, Bogoslof region, waters off Adak Island (the Aleutian Islands), and Gulf of Alaska (Mulligan et al., 1992). T.G.Mulligan and his team found two dominating genotypes in 39 and 21 individuals out of the overall 168 samples. Tests of haplotype frequencies in mitochondrial DNA showed considerable distinctions between pollock from waters off Adak Island and the rest. The differentiation level was low (0.019), but typical of marine fish populations (Bailey et al., 1999 b). Studies of the pollock allozyms yielded the same level of differentiation. Mitochondrial DNA allowed for the first genetic demonstration of similarity between pollock from the Bogoslof region, and that from the southern part of the «Donut Hole» (Grant, Utter, 1980). In the late 1980s – early 1990s, Japanese researches (K.Numachi and T.Kobayashi) identified variation in mitochondrial DNA among pollock shoals from the West, Northeast, and Southeast Bering Sea shelves. It is noteworthy that the Japanese did not find any difference between pollock from the Central Bering Sea and that from the mentioned regions (ref. Yanagimoto, 2002). Absence of genetic distinction between pollock from deepwater regions and that inhabiting waters of the continental slope and shelf could be associated with the period of active migrations of pollock from virtually all the Bering Sea populations to the central part of the sea (see Chapter 2). Analysis of nucleotide sequences in mitochondrial and nuclear DNA made a distinction by mitochondrial gene loci coding synthesis of cytochrome-b and 6-ATPase between pollock from Gulf of Alaska and the Bering Sea pollock, as well as between populations within each of these regions. There was no distinction by nuclear gene LDH-A (Quattro, Powers, 1994). Later G.F.Shields and G.R.Gust (1995) analyzed 511 nucleotides of mitochondrial DNA in 162 pollock individuals sampled from the West, Northwest, Southeast, and Central Bering Sea, waters off the Aleutian Islands, and in Gulf of Alaska. The pairwise comparison did not yield difference in heterozygosity of any stock. However, when samples from the western regions were grouped together with those from the northwestern waters, it became obvious that there was small difference between this larger group and pollock sampled in the South East Bering Sea and Gulf of Alaska. Thus, the Americans managed to demonstrate genetic difference of the western pollock stocks, including those in the north, from the eastern pollock (Shields, Gust, 1995). Unfortunately, collection of samples for the genetic analysis did not coincide with the spawning period, making interpretation of results very difficult. Neither did J.E.Seeb and his team found distinction between structure of mitochondrial DNA in pollock from the Shelikhof Bay and that from Gulf of Alaska. The Bogoslof pollock differed from the mentioned stocks in haplotype frequencies (Seeb et al., 2002). Researchers from the Institute of Marine Biology and TINRO (Brykov et al., 2002) analyzed polymorphism of mitochondrial DNA (amplified by the chain reaction) in pollock from five spawning shoals located in Ozernoy Inlet, Olyutor Bay, Anadyr Gulf, the Koryak and Navarin regions. Overall, the selected three loci corresponded to almost a half of the mitochondrial DNA genome (comprising >7,000 nucleotide pairs). From the set of fifteen enzymes the geneticists chose six (Ama871, VspI, MspI, RsaI, HaeIII, HinfI). These studies help identify a great variety of haplotypes. Cluster analysis with determination of genetic distances showed that the Anadyr Gulf pollock was isolated from other stocks. Korean scientists S.-S. Kim and W.-S. Yang (2002) studied fragments of mitochondrial DNA coding eight digestive endonucleases (six of them were polymorphic). All the analyzed samples (i.e. from the Pribiloff and Bogoslof regions, the Central Okhotsk Sea, and the Pacific waters off the North Kurils) were different. Comprehensive analysis of nucleotide sequences in mitochondrial DNA made by Japanese scientists who used material from ten individuals of pollock sampled in the Bering and Japanese seas confirmed appropriateness of this technique for population studies. Genes ND1 and ND5 were highly polymorphic; therefore, they could be very promising indicators for identification of the pollock population structure (Yanagimoto et al., 2004).

Thus, the majority of researchers have succeeded in use of mitochondrial DNA and proteins to identify an apparent genetic structurization of the Bering Sea pollock aggregations, which more or less correlates with geographical distances between shoals. Hence, modern research techniques reveal that the pollock migration activity is much smaller than it was suggested earlier. Otherwise, there were no genetic variation between pollock aggregations from the West, North, East, and South Bering Sea.

**Studies of polymorphism in genomic DNA, including microsatellite sequences.** Progress in development of tools to visualize polymorphism of genome DNA made possible the real breakthrough in assessment of individual and population genetic variability, and, consequently, rapid increase in number of applied genetic markers. Generally, molecule markers should satisfy the following requirements: high level of polymorphism, codominant inheritance, frequent occurrence and uniform distribution in genome, selective neutrality, easy accessibility, allowance for automated analysis, etc. (Shubina et al., 2004 a). At present there are no markers which would satisfy all these criteria simultaneously, nevertheless, the nature of the determined task allows to choose the most appropriate system. The technique of simultaneous identification of numerous highly variable loci through hybridization of specific multiloci samples with restriction fragments divided by electrophoresis was called «fingerprinting DNA». The most important achievement in development of this technique was determination of polymorphism with the polymerase chain reaction (PCR). The PCR-based fingerprinting implies *in vitro* amplification of particular sequences of DNA with specially or randomly chosen oligonucleotide triggers (or primers) (micro/minisatellite analysis and the RAPD strategy, respectively).

All attempts to study the pollock genome DNA with random amplification of polymorphic fragments using PCR turned out unsuccessful because it was very difficult to repeat the obtained results and to satisfy the PCR conditions precisely. Japanese scientists failed to identify primers which could be effective in the pollock population analysis (Yanagimoto, 2002).

Application of microsatellite sequences of DNA as markers of the spatial and temporal distribution of pollock stocks could yield a most objective distribution pattern because it was found that these DNA fragments are characterized by a very high level of polymorphism associated with an elevated frequency of mutations. In case of even partial isolation of populations, genetic markers with rapidly evolving genes are able to accumulate variations in a shorter time. While analysis of slowly evolving genes (e.g. genes responsible for protein synthesis) could help identify population differences which have been developing for tens of thousands — millions of years, analysis of microsatellite loci identifies variations which have been developed for less than 10,000 years (Grant, 2002).

Genomic microsatellite loci consist of tandemly (head-tail) repeated sequences with the main motive of two or six nucleotide pairs. The length of such microsatellite loci attains 200—300 nucleotide pairs. Microsatellite loci are characterized by a relatively low frequency and dispersion over numerous genomic loci. These very sequences are associated with «hot spots» of the genome mutations. Microsatellites evolve at the expense of shift during complementary pairing of a newly synthesized DNA chain and a matrix one at an early point of replication. The mutation rate of microsatellite DNA totals $10^{-2}-10^{-4}$ events per locus per generation. Microsatellite markers are codominant by nature, i.e. each individual includes a specific set of two alleles (one on each chromosome). Analysis of the pollock intraspecies structure is based on comparative assessment of the allele frequency distribution in microsatellite loci from various samples.

Early studies of microsatellite loci from pollock captured during the feeding period failed to differentiate populations because the feeding period is the time when individuals of various genesis mix together (Villa, 1999; Grant, 2002; Olsen et al., 2002; Seeb et al., 2002). Comparison of informative merits of three genetic techniques (i.e. identification of allozym polymorphism, analysis of the mitochondrial DNA structure, and studies of microsatellite sequences) applied to assess the population structure of pollock from Kronotsky Bay, the South East Bering Sea, and Gulf of Alaska in 1977–1999 showed the following. Data obtained from analysis of two allozyms (superoxide dismutase-2 and mannose-6-phosphate isomerase) were similar to those yielded by the mitochondrial DNA analysis: there was a significant genetic distinction between pollock population in the Bering Sea and that in Gulf of Alaska. Despite a high level of polymorphism, 14 microsatellite loci in pollock from regions located geographically far from each other had minor variations (Olsen et al., 2002; O'Reilly et al., 2004). Such results could be explained by imperfection of techniques applied at early stages of genetic studies as well as search for the most rapidly evolving genes in the Bering Sea pollock.

At later stages, studies of microsatellite sequences were made with improved technologies and samples collected from the pollock spawning stocks (O'Reilly et al., 2000, 2002; Shubina et al., 2002; 2004 a, b; 2005; Shubina, Glubokov, 2003). A.I.Brooker with coauthors were one of the first to obtain significant distinction between pollock from the Bering Sea pollock and that from Gulf of Alaska by two microsatellite loci (Gmo-145 and Gmo-2; were first identified in cod) (Brooker et al., 1994). Another group of scientists succeeded to show a marked genetic structurization applying microsatellite loci of DNA from pollock stocks of the Koryak shelf, waters off Unimak Island, Funk Bay, Gulf of Alaska, and the port of Townsand (California) known to accommodate various pollock populations (O'Reilly et al., 2002).

M.Canino and his coauthors (2002) compiled results of previous studies of 14 DNA microsatellite sequences in pollock. For several populations, M.Canino showed correspondence between the degree of differentiation of the isolation-by-distance model and inbreeding coefficient $F_{st}$ within the range of 0.013–0.018 (Canino et al., 2002). This value of the coefficient characterizes the population level of differentiation for marine fish species (Grant, Utter, 1980; Bailey et al., 1999 a; Canino et al., 2002).

Studies of DNA microsatellite sequences were mostly focused on the East

Bering Sea pollock. No studies of such kind were performed for pollock of the Koryak plateau. Genetic samples from the Navarin waters and the Karagin subzone of the East Kamchatka zone were fragmentary. Therefore, in 1997–2004, we collected DNA samples for analysis of nucleotide sequences, including microsatellite ones, in pollock from most regions within Russian EEZ in the Bering Sea and water off the North Kurils. In the East Bering Sea, samples were collected in February–March 2004 during the survey aboard the AFSC R/V *Miller Freeman* and kindly sent to us for analysis by the AFSC researcher N.Williamson. Sites of sample collection are presented in Figure 6.1.

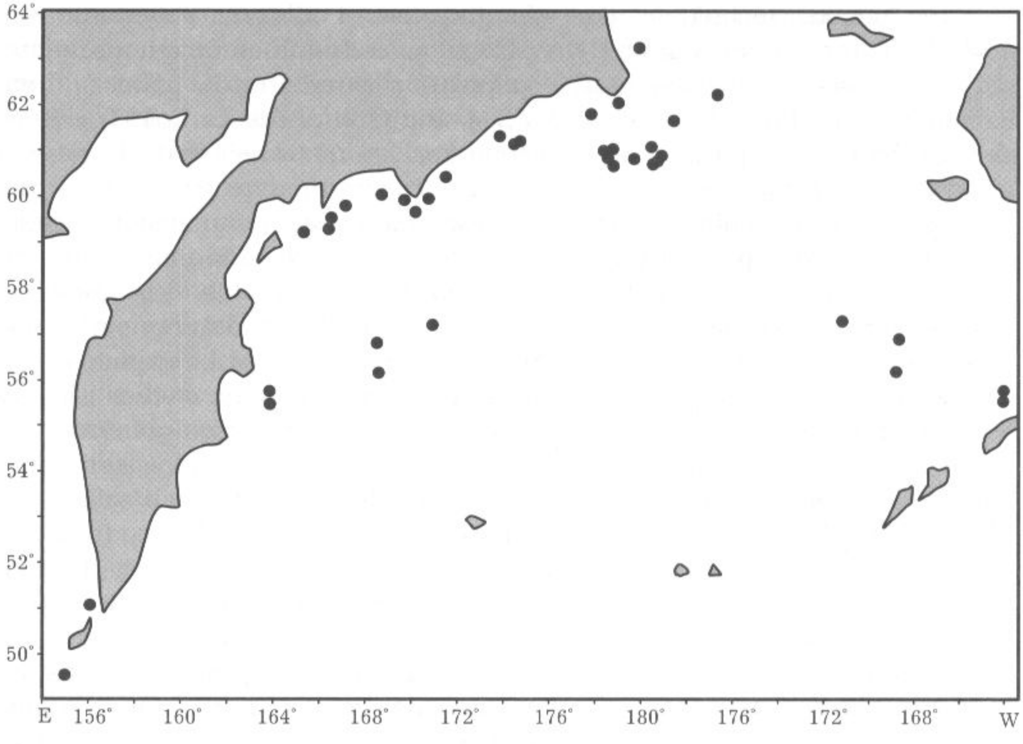


**Fig. 6.1.** Pollock genetic sampling sites, 1997–2004

Our joint investigation with scientists from Belozerskyi's Research Institute of Physical-Chemical Biology of Moscow University continues a series of studies aimed at genetic identification of the Bering Sea spawning pollock aggregations with DNA markers, including microsatellite sequences (Glubokov, 2003; Shubina, Glubokov, 2003; Shubina et al., 2002, 2003, 2004 a, b). The general level of polymorphism in genomic DNA of pollock was preliminary assessed with the PCR-RAPD. The analysis revealed a tendency towards clustering (Glubokov, 2003), though the grouping confidence at 1,000 Bootstrap steps did not exceed 30%. Nevertheless, additionally to this obviously insufficient level of polymorphism, application of some statistical approaches (e.g. random sequencing of samples did not change the clusters. There was no correlation between clusters and geographical locations of pollock schools. Population-genetic analysis by the dominating type revealed a low heterozygosity which varied from 0.12 (pollock from waters of the Shirshov underwater Ridge) – 0.15 (the Navarin aggregation). Portion of polymorphic loci made around 40% and this portion did not vary significantly for different geographical regions. Test of the population differentiation by frequency of recessive (zero) genotypes with $\chi^2$ criterion was negative due to a large number of rare genotypes. Nevertheless differentiation of all populations by Fst made 0.0658. The unbiased estimate remained unchanged after the jacknife procedure. Meanwhile the Bootstrap analysis showed a very wide range of variability (0.0292 – 0.111) in attaining the 95%-level of significance. Distant and statistical analyses of the PCR-RAPD showed absence of correspondence between polymorphism of RAPD-markers and genetic differentiation of the Bering Sea pollock and necessity of application of some more polymorphic markers, namely de-, tri-, and tetranucleotide microsatellite sequences (O'Reilly et al., 2000).

For analysis, we selected 11 microsatellite loci: Tch5, Tch10, Tch12, Tch13, Tch14, Tch15, Tch17, Tch18, Tch19, Tch20, and Tch22 which were identified by P.O'Reilly with coauthors (2000). Their nucleotide sequences and primers are shown below (F=forward and R=reverse).

| | | |
|---|---|---|
| Tch5 | $(GATA)_{14}$ | F: gcc tta ata tca cgc aca<br>R: tcg cat tga gcc tag ttt |
| Tch10 | $(GGCT)_6$CTCT $(GTCT)_2$ | F: gtc tct atg tct gtc ttt cta ttt g<br>R: acg aaa ccc aac cct gat t |
| Tch12 | $(GGTT)_{22}$ | F: caa ttt gtc agc ctc tgt tac c<br>R: agt aca gct tga ttg ttt ctg gg |
| Tch13 | $(GT)_9$ | F: ttt ccg atg agg tca tgg<br>R: agt aca gct tga ttg ttt ctg gg |
| Tch14 | $(GAAA)_{31}$ | F: cat aca ttg gtc act ctt tct tac<br>R: aaa ctg ata tac gcc caa ct |
| Tch15 | $(GA)_3(CA)_2$GACA $(GA)_5$CAGATA$(GA)_8$ | F: aaa ctt cac ctg acc aac<br>R: gca aca caa ctt aat cat ct |
| Tch17 | $(GTCT)_{27}$ | F: gtc tgt ctg ccc gtg agt<br>R: agc cag tgg cat ttg ttc |

| | | |
|---|---|---|
| Tch18 | $(GT)_{15}$ | F: gga gat ggt gct aac tgg<br>R: aac gca cat gca cat acg. |
| Tch19 | $(GTCT)_{15}$ | F: tat gct gat tgg tta ggc<br>R: gat cat ttg ttt cag aga gc |
| Tch20 | $(GA)_5GGGAA(GGAA)_3GGAT(GGAA)_2\ GGAAT(GAAA)_{10}GAAG(GAAA)_5$ | F: aca ttg taa acg gcg att c<br>R: tgg tta gtc tga gac cca g |
| Tch22 | $(GACA)_6$ | F: atc ata tct ggc caa gtt c<br>R: ctc tct ctg aat ccc tct g |

Typing of allele variants was made with KODAK 1D Image Analysis Software. This software determines absolute sizes of microsatellite alleles during the input of data on the size of the marker fragments. This makes it possible to integrate data bases. Figure 6.2 presents an example of a typing stage.

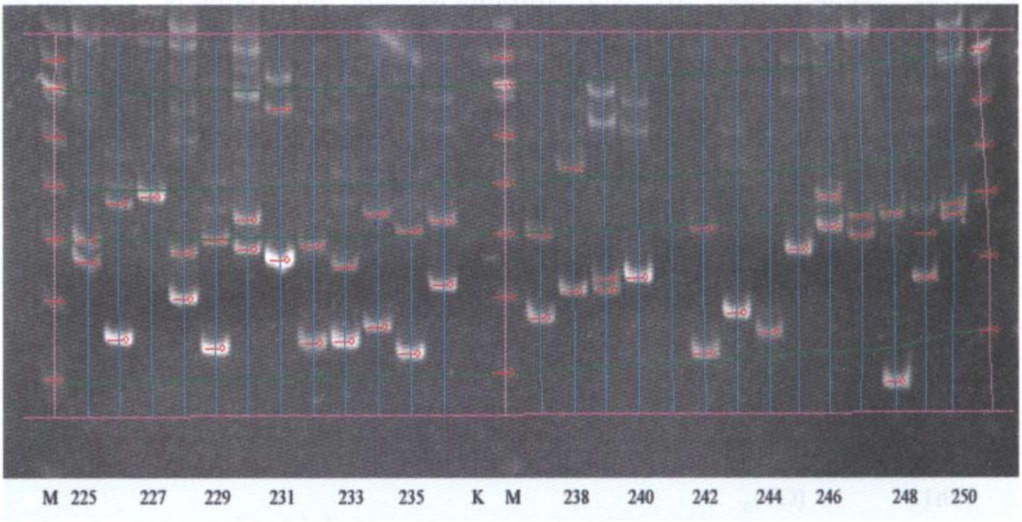


**Fig. 6.2.** Stage of typing of Tch19

The products of typing of loci Tch13, Tch15, Tch18, and Tch22 were chemically unstable, while typing of Tch17 and Tch20 was very likely to yield an erroneous result. Therefore, these six loci were excluded from the analysis.

Tables 6.1 – 6.5 summarize results of typing of the DNA specimen in other loci (Tch5, Tch10, Tch12, Tch14, Tch19). The left column presents the allele position in nucleotide pairs. Next columns presents the allele frequencies in the total collection and in each of the analyzed samples. The tables were used to plot histograms of distribution of allele frequencies.

**Table 6.1.** Results of genotyping in Tch5, by area

| N.p.* | Total | North Kurils | Karagin | Olyutor | Shirshov | Navarin | The East Bering Sea |
|---|---|---|---|---|---|---|---|
| 186 | 4 | 1 | 0 | 1 | 0 | 2 | 0 |
| 190 | 5 | 2 | 0 | 0 | 2 | 1 | 0 |
| 194 | 6 | 1 | 0 | 0 | 2 | 1 | 2 |
| 198 | 10 | 1 | 2 | 1 | 2 | 3 | 1 |
| 202 | 7 | 0 | 2 | 1 | 2 | 1 | 1 |
| 206 | 5 | 0 | 0 | 1 | 2 | 1 | 1 |
| 210 | 13 | 0 | 0 | 1 | 6 | 0 | 6 |
| 214 | 7 | 1 | 1 | 0 | 3 | 1 | 1 |
| 218 | 12 | 0 | 0 | 4 | 4 | 3 | 1 |
| 222 | 18 | 1 | 0 | 3 | 9 | 1 | 4 |
| 226 | 20 | 1 | 2 | 6 | 5 | 6 | 0 |
| 230 | 34 | 4 | 2 | 3 | 16 | 4 | 5 |
| 234 | 40 | 0 | 6 | 5 | 11 | 4 | 14 |
| 238 | 37 | 0 | 1 | 9 | 11 | 10 | 6 |
| 242 | 43 | 5 | 4 | 11 | 11 | 7 | 5 |
| 246 | 57 | 8 | 1 | 12 | 18 | 11 | 7 |
| 250 | 36 | 3 | 5 | 6 | 10 | 7 | 5 |
| 254 | 48 | 3 | 2 | 11 | 12 | 8 | 12 |
| 258 | 39 | 2 | 5 | 10 | 8 | 10 | 4 |
| 262 | 28 | 4 | 1 | 5 | 6 | 5 | 7 |
| 266 | 38 | 1 | 4 | 10 | 8 | 10 | 5 |
| 270 | 23 | 0 | 3 | 7 | 9 | 2 | 2 |
| 274 | 23 | 2 | 3 | 6 | 4 | 4 | 4 |
| 278 | 16 | 0 | 3 | 5 | 4 | 3 | 1 |
| 282 | 12 | 0 | 2 | 2 | 3 | 3 | 2 |
| 286 | 8 | 0 | 0 | 4 | 1 | 2 | 1 |
| 290 | 7 | 0 | 0 | 1 | 3 | 2 | 1 |
| 294 | 23 | 0 | 0 | 1 | 2 | 0 | 0 |
| 298 | 23 | 0 | 0 | 0 | 4 | 0 | 0 |
| 302 | 16 | 0 | 1 | 0 | 2 | 0 | 0 |

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*Number of nucleotide pairs.

**Table 6.2.** Results of genotyping in Tch10, by area

| N.p. | Total | North Kurils | Karagin | Olyutor | Shirshov | Navarin | The East Bering Sea |
|---|---|---|---|---|---|---|---|
| 137 | 6 | 0 | 0 | 1 | 1 | 2 | 2 |
| 139 | 12 | 0 | 2 | 2 | 1 | 2 | 5 |
| 141 | 7 | 0 | 1 | 5 | 1 | 0 | 0 |
| 143 | 17 | 0 | 1 | 3 | 2 | 7 | 4 |
| 145 | 19 | 2 | 1 | 2 | 5 | 7 | 2 |
| 147 | 21 | 0 | 2 | 4 | 8 | 3 | 4 |
| 149 | 28 | 1 | 4 | 6 | 8 | 9 | 0 |
| 151 | 32 | 2 | 2 | 4 | 14 | 6 | 4 |
| 153 | 69 | 0 | 6 | 15 | 24 | 14 | 10 |
| 155 | 88 | 6 | 6 | 26 | 28 | 13 | 9 |
| 157 | 106 | 10 | 9 | 17 | 29 | 18 | 23 |
| 159 | 24 | 2 | 1 | 6 | 6 | 2 | 7 |
| 161 | 12 | 3 | 1 | 2 | 3 | 1 | 2 |
| 163 | 8 | 1 | 1 | 1 | 4 | 1 | 0 |
| 165 | 7 | 0 | 1 | 2 | 2 | 2 | 0 |
| 167 | 21 | 4 | 1 | 7 | 8 | 1 | 0 |
| 169 | 15 | 0 | 2 | 0 | 5 | 4 | 4 |
| 171 | 31 | 4 | 4 | 6 | 3 | 7 | 7 |
| 173 | 14 | 1 | 3 | 2 | 3 | 3 | 2 |
| 175 | 8 | 0 | 0 | 0 | 1 | 1 | 6 |
| 177 | 7 | 1 | 0 | 2 | 4 | 0 | 0 |
| 179 | 5 | 0 | 0 | 1 | 1 | 3 | 0 |
| 181 | 3 | 1 | 0 | 0 | 1 | 0 | 1 |
| 183 | 8 | 1 | 0 | 4 | 2 | 1 | 0 |
| 185 | 6 | 0 | 0 | 1 | 3 | 2 | 0 |
| 187 | 3 | 1 | 0 | 1 | 0 | 1 | 0 |
| 189 | 3 | 0 | 1 | 0 | 1 | 0 | 1 |
| 195 | 4 | 0 | 0 | 1 | 3 | 0 | 0 |
| 197 | 5 | 0 | 0 | 2 | 1 | 0 | 2 |
| 199 | 6 | 0 | 2 | 2 | 1 | 1 | 0 |
| 203 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| 209 | 4 | 0 | 1 | 0 | 2 | 0 | 1 |
| 213 | 2 | 0 | 0 | 0 | 1 | 1 | 0 |

**Table 6.3.** Results of genotyping in Tch12, by area

| N.p | Total | North Kurils | Karagin | Olyutor | Shirshov | Navarin | The East Bering Sea |
|---|---|---|---|---|---|---|---|
| 118 | 4 | 4 | 0 | 0 | 0 | 0 | 0 |
| 122 | 2 | 1 | 0 | 0 | 0 | 0 | 1 |
| 126 | 20 | 1 | 1 | 2 | 7 | 2 | 7 |
| 130 | 212 | 8 | 21 | 51 | 57 | 38 | 37 |
| 134 | 131 | 9 | 12 | 19 | 46 | 31 | 14 |
| 138 | 112 | 7 | 15 | 27 | 29 | 17 | 17 |
| 142 | 51 | 2 | 2 | 11 | 19 | 9 | 8 |
| 146 | 54 | 6 | 0 | 13 | 15 | 10 | 10 |
| 150 | 14 | 1 | 1 | 2 | 5 | 3 | 2 |
| 154 | 3 | 1 | 0 | 0 | 0 | 2 | 0 |
| 158 | 1 | 0 | 0 | 1 | 0 | 0 | 0 |

Locus Tch5 revealed minor variations in histograms plotted for different samples.

There was a minor variation in distribution of allele frequencies of Tch10 between samples from the Olyutor-Shirshov and East Bering Sea stocks. There are also marked differences with the small sample taken from waters off the North Kurils. However, the profiles are generally similar.

Locus Tch12 showed distinction between the North Kuril and Karagin samples, however, both samples were small.

The East Bering Sea samples were characterized by a small shift in the allele frequency distribution in Tch14. However, this change went smooth within the sample series from the Karagin-Olyutor-Shirshov-Navarin-East Bering Sea aggregations. The cumulative sample had distribution close to normal.

Like other loci, Tch19 had no significant variations in distribution of allele frequencies.

Table (6.6) summarizes main genetic characteristics of samples and microsatellite loci. Stars marks loci with the largest variations.

The Hardy-Weinberg equillibrium was inherent in Tch5 and Tch10 from all samples but one (i.e. Tch5 from the East Bering Sea sample). Neither did histograms of the allele frequency distribution showed variations between loci in number of rare alleles capable to cause a shift of the actual heterozygosity value.

**Table 6.4.** Results of genotyping in Tch14, by area

| N.p. | Total | North Kurils | Karagin | Olyutor | Shirshov | Navarin | The East Bering Sea |
|---|---|---|---|---|---|---|---|
| 120 | 1 | 0 | 0 | 0 | 0 | 1 | 0 |
| 124 | 3 | 1 | 0 | 1 | 0 | 0 | 1 |
| 128 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| 132 | 2 | 0 | 0 | 1 | 0 | 1 | 0 |
| 136 | 4 | 1 | 0 | 1 | 1 | 0 | 1 |
| 140 | 6 | 0 | 0 | 2 | 1 | 1 | 2 |
| 144 | 7 | 2 | 1 | 0 | 3 | 0 | 1 |
| 148 | 10 | 0 | 2 | 3 | 3 | 1 | 1 |
| 152 | 7 | 2 | 3 | 1 | 2 | 1 | 1 |
| 156 | 18 | 2 | 3 | 5 | 3 | 7 | 1 |
| 160 | 22 | 1 | 2 | 5 | 7 | 6 | 1 |
| 164 | 27 | 2 | 5 | 6 | 6 | 3 | 5 |
| 168 | 42 | 0 | 6 | 8 | 14 | 7 | 7 |
| 172 | 49 | 4 | 6 | 10 | 21 | 3 | 5 |
| 176 | 46 | 9 | 1 | 9 | 13 | 10 | 4 |
| 180 | 48 | 2 | 4 | 14 | 9 | 11 | 8 |
| 184 | 60 | 3 | 7 | 12 | 13 | 14 | 11 |
| 188 | 59 | 1 | 6 | 9 | 23 | 11 | 9 |
| 192 | 68 | 4 | 6 | 13 | 17 | 5 | 23 |
| 196 | 36 | 3 | 1 | 11 | 11 | 8 | 2 |
| 200 | 39 | 1 | 2 | 4 | 13 | 12 | 7 |
| 204 | 15 | 1 | 1 | 5 | 5 | 1 | 2 |
| 208 | 7 | 0 | 0 | 2 | 3 | 0 | 2 |
| 212 | 7 | 1 | 0 | 2 | 2 | 1 | 1 |
| 216 | 5 | 0 | 0 | 0 | 4 | 1 | 0 |
| 220 | 9 | 0 | 0 | 2 | 1 | 3 | 3 |
| 224 | 2 | 0 | 0 | 0 | 2 | 0 | 0 |

All studied samples were characterized by the heterozygote deficit to some extent (Table 6.6). P.O'Reilly with coauthors who developed this set of microsatellite markers, had to admit that some loci (including Tch14 and Tch19) are characterized by low heterozygosity. According their opinion this fact could be explained by peculiarities of the analytical techniques, i.e. in the process of electrophoresis long allele were screened by short ones as well as by a large number of 0-alleles (mutations in flanking sequences) (O'Reilly et al., 2004).

**Table 6.5.** Results of genotyping in Tch19, by area

| N.p. | Total | North Kurils | Karagin | Olyutor | Shirshov | Navarin | The East Bering Sea |
|---|---|---|---|---|---|---|---|
| 90 | 2 | 0 | 0 | 0 | 1 | 1 | 0 |
| 98 | 2 | 0 | 1 | 0 | 0 | 1 | 0 |
| 102 | 4 | 0 | 0 | 0 | 0 | 4 | 0 |
| 106 | 25 | 3 | 2 | 4 | 9 | 6 | 1 |
| 110 | 41 | 1 | 1 | 6 | 11 | 11 | 11 |
| 114 | 35 | 2 | 4 | 5 | 15 | 8 | 0 |
| 118 | 53 | 2 | 5 | 8 | 17 | 10 | 11 |
| 122 | 34 | 1 | 4 | 5 | 13 | 7 | 4 |
| 126 | 45 | 5 | 8 | 8 | 9 | 9 | 6 |
| 130 | 60 | 5 | 5 | 15 | 17 | 10 | 8 |
| 134 | 69 | 7 | 6 | 15 | 22 | 10 | 9 |
| 138 | 58 | 1 | 3 | 18 | 19 | 6 | 11 |
| 142 | 45 | 0 | 6 | 14 | 13 | 7 | 5 |
| 146 | 44 | 3 | 1 | 9 | 19 | 3 | 9 |
| 150 | 27 | 5 | 2 | 6 | 4 | 3 | 7 |
| 154 | 21 | 3 | 1 | 7 | 4 | 3 | 3 |
| 158 | 18 | 0 | 2 | 2 | 3 | 4 | 7 |
| 162 | 12 | 0 | 1 | 0 | 3 | 5 | 3 |
| 166 | 5 | 0 | 0 | 2 | 1 | 0 | 2 |

The population differentiation was analyzed by genotype variances, allele diversity, and variances of genetic frequencies. The main sample significantly different in both genotype, and allele variants was that from waters off the North Kurils (Table 6.7). It was followed by samples from the East Bering Sea. Samples from the Northwest Bering Sea did not reveal any noticeable distinction. Genotype differntiations were only found in Tch5, Tch10, and Tch12 with the inherent Hardy-Weinberg equillibrium.

Population differentiation was quantitatively assessed by standardized variance in gene frequencies which is found as a difference between the total population variance and the interpopulation one. Today this indicator is also determined for multiallele loci (Gst) (Nei, Li, 1973) or absolute values of allele variants in microsatellite loci (Rst) (Slatkin, 1995), however, the majority of scientists still prefer the traditional value of the indicator (i.e. $F_{st}$), introduced by S.Wright (1951).

**Table 6.6.** Main genetic characteristics of samples and microsatellite loci. N – number of specimens examined; Na – number of alleles in locus; R – range of the allel size variations in nucleotide pairs; He – expected heterozygosity; Ho – observed heterozygosity

| Samples | Loci | | | | | |
|---|---|---|---|---|---|---|
| | | Tch 5 | Tch 10 | Tch 12 | Tch 14 | Tch 19 |
| North Kurils | N | 20 | 20 | 20 | 20 | 19 |
| | Na | 16 | 15 | 10 | 13 | 12 |
| | R | 186–274 | 145–187 | 118–154 | 116–212 | 106–162 |
| | He | 0.90 | 0.88 | 0.84 | 0.90 | 0.88 |
| | Ho | 0.90 | 0.85 | $0.60^{*}$ | $0.60^{***}$ | 0.74 |
| Karagin | N | 25 | 26 | 26 | 25 | 26 |
| | Na | 19 | 21 | 7 | 16 | 16 |
| | R | 198–302 | 139–209 | 126–150 | 144–204 | 94–162 |
| | He | 0.93 | 0.92 | 0.70 | 0.90 | 0.91 |
| | Ho | 0.96 | 1.00 | 0.65 | $0.56^{***}$ | 0.81 |
| Olyutor | N | 63 | 63 | 63 | 63 | 62 |
| | Na | 25 | 26 | 8 | 22 | 15 |
| | R | 186–294 | 137–199 | 126–158 | 116–220 | 106–166 |
| | He | 0.94 | 0.91 | 0.75 | 0.93 | 0.91 |
| | Ho | 0.83 | 0.87 | $0.48^{***}$ | $0.75^{***}$ | $0.66^{***}$ |
| Shirshov | N | 90 | 90 | 89 | 89 | 90 |
| | Na | 29 | 33 | 7 | 24 | 17 |
| | R | 190–302 | 137–213 | 126–150 | 124–224 | 90–166 |
| | He | 0.95 | 0.91 | 0.79 | 0.93 | 0.92 |
| | Ho | 0.89 | 0.81 | $0.61^{*}$ | $0.65^{***}$ | $0.63^{***}$ |
| Navarin | N | 56 | 56 | 56 | 54 | 54 |
| | Na | 26 | 25 | 8 | 21 | 18 |
| | R | 186–290 | 139–209 | 126–154 | 112–220 | 90–162 |
| | He | 0.94 | 0.92 | 0.77 | 0.92 | 0.93 |
| | Ho | 0.85 | $0.84^{*}$ | $0.57^{**}$ | $0.70^{***}$ | $0.57^{***}$ |
| The East Bering Sea | N | 49 | 49 | 48 | 49 | 49 |
| | Na | 25 | 19 | 8 | 22 | 15 |
| | R | 194–290 | 137–209 | 122–150 | 119–224 | 106–166 |
| | He | 0.93 | 0.90 | 0.78 | 0.90 | 0.92 |
| | Ho | $0.80^{**}$ | 0.76 | 0.69 | $0.71^{*}$ | $0.45^{***}$ |

Genetic distances (Tables 6.8, 6.9) reveal that the main source of differentiation in the analyzed samples are samples collected in waters off the North Kurils. This corresponds well with the maximum geographical remotedness and isolation of the North Kuril pollock from the Bering Sea one.

**Table 6.7.** Pair differentiation of pollock samples by distribution of allele variants (below diagonal) and genotypes (above diagonal), in five microsatellite loci. P is probability of correspondence to 0-hypothesis on absence of differentiation (Fisher test); m – standard error

| Samples | Shirshov | | Olyutor | | Karagin | | Navarin | | North Kurils | | The East Bering Sea | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Locus | P/m | Locus | P/m | Locus | P/m | Locus | P/m | Locus | P/m | Locus | P/m |
| Shirshov | XXX | | | | | | | | Tch12 | 0.01594/0.00197 | Tch10 | 0.00090/0.00041 |
| Olyutor | | | XXX | | | | | | Tch5<br>Tch12 | 0.04512/0.0041<br>0.04517/0.00409 | Tch10 | 0.00029/0.00017 |
| Karagin | | | | | XXX | | | | Tch5<br>Tch12 | 0.01253/0.0015<br>0.01978/0.00166 | Tch12 | 0.04257/0.00299 |
| Navarin | Tch14 | 0.04299/0.00471 | Tch19 | 0.01767/0.00362 | | | XXX | | Tch10 | 0.02227/0.00261 | Tch10 | 0.03187/0.0036 |
| North Kurils | Tch12 | 0.00196/0.00056 | Tch12 | 0.00280/0.00105 | Tch5<br>Tch12<br>Tch14 | 0.01260/0.00203<br>0.00426/0.00099<br>0.00854/0.00166 | Tch10<br>Tch12<br>Tch14 | 0.01609/0.00259<br>0.03415/0.00321<br>0.02083/0.00328 | XXX | | Tch5 | 0.05510/0.00387 |
| The East Bering Sea | Tch10<br>Tch19 | 0.00071/0.00039<br>0.04406/0.00406 | Tch10 | 0.00022/0.00020 | | | Tch10<br>Tch14 | 0.01919/0.0038<br>0.01103/0.00249 | Tch5<br>Tch10<br>Tch12<br>Tch14<br>Tch19 | 0.03813/0.00525<br>0.00351/0.00109<br>0.02352/0.00252<br>0.01202/0.00216<br>0.03405/0.00304 | XXX | |

**Table 6.8.** Values of standardized interpopulation variance of allele frequences by distribution of allele frequences of five microsatellite loci of pollock calculated using GENEPOP and TFPGA. $F_{IT}$ – variance of allele frequencies in total undivided sample; $F_{IS}$ – interpopulation variance; $F_{ST}$ – standardized interpopulation variance

| Loci | Programm GENEPOP | | | Programm TFPGA | | |
|---|---|---|---|---|---|---|
| | Value of the indicators | | | | | |
| | $F_{IT}$ | $F_{ST}$ | $F_{IS}$ | $F_{IT}$ | $F_{ST}$ | $F_{IS}$ |
| Tch5 | 0.092193 | 0.001542 | 0.090791 | 0.0922 | 0.0015 | 0.00908 |
| Tch10 | 0.064332 | 0.002922 | 0.061589 | 0.0858 | 0.0026 | 0.0834 |
| Tch12 | 0.244932 | 0.002893 | 0.242741 | 0.2460 | 0.0031 | 0.2436 |
| Tch14 | 0.270590 | 0.003663 | 0.267908 | 0.2706 | 0.0037 | 0.2679 |
| Tch19 | 0.316928 | −0.000785 | 0.317464 | 0.3313 | −0.007 | 0.3318 |
| Mean | 0.1961 | 0.0020 | 0.1945 | 0.2036 | 0.0020 | 0.2020 |

As far as Nei distances are derivatives of distances expressed in $F_{st}$ units, we should analyze unbiased values adjusted to the sample size.

In all samples from the Bering Sea there was a clear dependence of genetic distances on geographical remoteness of schools from each other (Table 6.10) (Glubokov et al., 2002; Shubina, Glubokov, 2003; Shubina et al., 2005). For example, genetic distances of the North Kuril pollock were the maximum: 0.089 (distance from the Shirshov sample) – 0.157 (distance from the East Bering Sea sample). Within the Bering Sea, the maximum Nei distance was found between the Navarin and the East Bering Sea pollock (0.0627). A small differences (0.0011 – 0.0150) were obtained between pollock in Karagin Bay and that in waters of the Shirshov underwater ridge and Koryak plateau (Fig. 6.3, 6.4) confirming the hypothesis that these regions accommodated a common population of the West Bering Sea pollock. The differentiation level of >0.018 was assumed typical of populations of marine fish species with a prominent genetic drift (Bailey et al., 1999 a). Consequently, the identified by us level of variations in heterozygosity of the pollock DNA microsatellites allowed to differentiate the West Bering Sea, Navarin, East Bering Sea, and North Kuril (East Kamchatka) populations among all studied pollock groupings.

**Table 6.9.** Value of standardized interpopulation variances ($F_{st}$) by individual loci and in total in five loci.
1 – Shirshov sample; 2 – Olyutor sample; 3 – North Kurils sample; 4 – Karagin sample; 5 – Navarin sample;
6 – East Bering Sea sample

| | Tch5 | | | | | Tch10 | | | | | Tch12 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2 | 3 | 4 | 5 | 6 | 2 | 3 | 4 | 5 | 6 | 2 | 3 | 4 | 5 | 6 |
| 1 | -0.0004 | 0.0034 | 0.0035 | 0.0000 | 0.0008 | -0.0014 | 0.0091 | 0.0043 | -0.0002 | 0.0083 | 0.0060 | 0.0025 | 0.0082 | -0.0076 | 0.0027 |
| 2 | | 0.0058 | -0.0050 | -0.0068 | 0.0040 | | 0.0086 | -0.0023 | 0.0032 | 0.0137 | | 0.0182 | -0.0007 | 0.0050 | -0.0082 |
| 3 | | | 0.0208 | 0.0046 | 0.0136 | | | 0.0037 | 0.0105 | 0.0060 | | | 0.0294 | 0.0020 | 0.0141 |
| 4 | | | | -0.0010 | 0.0030 | | | | -0.0096 | -0.0017 | | | | 0.0060 | 0.0071 |
| 5 | | | | | 0.0050 | | | | | 0.0040 | | | | | 0.0035 |

| | Tch14 | | | | | Tch19 | | | | | All loci | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2 | 3 | 4 | 5 | 6 | 2 | 3 | 4 | 5 | 6 | 2 | 3 | 4 | 5 | 6 |
| 1 | -0.0011 | 0.0065 | -0.0062 | 0.0033 | 0.0080 | -0.0024 | 0.0048 | -0.0020 | -0.0017 | -0.0008 | -0.0001 | 0.0053 | -0.0004 | -0.0010 | 0.0038 |
| 2 | | 0.0017 | -0.0046 | -0.0008 | 0.0050 | | 0.0044 | -0.0021 | 0.0026 | -0.0013 | | 0.0074 | -0.0021 | 0.0005 | 0.0030 |
| 3 | | | 0.0154 | 0.0090 | 0.0207 | | | -0.0012 | 0.0024 | 0.0044 | | | 0.0133 | 0.0058 | 0.0117 |
| 4 | | | | 0.0045 | -0.0029 | | | | -0.0090 | 0.0013 | | | | -0.0019 | 0.0012 |
| 5 | | | | | 0.0154 | | | | | -0.0030 | | | | | 0.0050 |

**Table 6.10.** Pairwise Nei genetic distances (original, disregarding sample size – above diagonal and unbiased sample size considered – below diagonal) between various groupings of pollock, by 5 microsatellite loci

| Groupings | Shirshov | Olyutor | North Kurils | Karagin | Navarin | The East Bering Sea |
|---|---|---|---|---|---|---|
| Shirshov | xxx | 0.0701 | 0.2206 | 0.1128 | 0.0708 | 0.1137 |
| Olyutor | 0.0121 | xxx | 0.2375 | 0.1061 | 0.0906 | 0.1148 |
| North Kurils | 0.0890 | 0.0987 | xxx | 0.3331 | 0.2492 | 0.3042 |
| Karagin | 0.0150 | 0.0011 | 0.1545 | xxx | 0.11185 | 0.1441 |
| Navarin | 0.0045 | 0.0172 | 0.1022 | 0.0053 | xxx | 0.1445 |
| The East Bering Sea | 0.0473 | 0.0412 | 0.1570 | 0.0307 | 0.0627 | xxx |

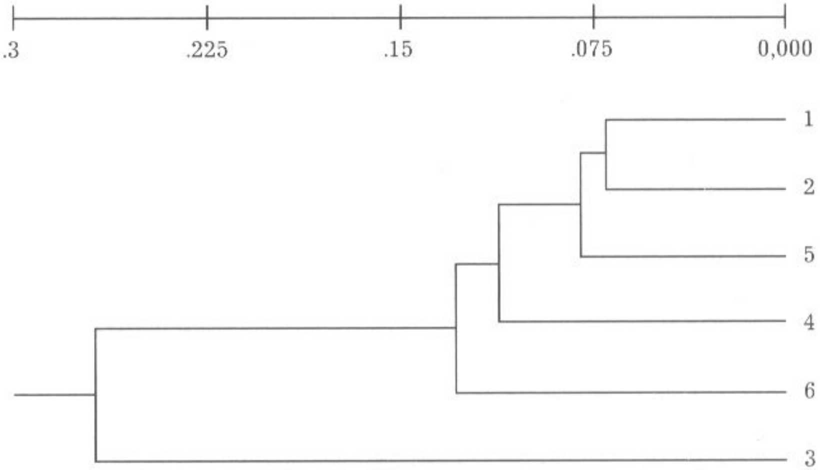

**Fig. 6.3.** UPGMA dendrogram of Nei genetic distances between various groupings of pollock. Sample: *1* – Shirshov; *2* – Olyutor; *3* – North Kurils; *4* – Karagin sample; *5* – Navarin; *6* – East Bering Sea

Summarizing the carried out studies of the DNA microsatellite loci in pollock from the Bering Sea and waters off the North Kurils, it could make the following conclusion. Verification by the Hardy-Weinberg law confirmed genetic equillibrium of all the studied groupings. Analysis of allele frequencies revealed genetic structuredness of pollock from the Bering Sea and waters off the North Kurils. Quantitative analysis of the differentiation allowed to identify the East Kamchatka, West Bering Sea, Navarin, and East Bering Sea pollock populations.

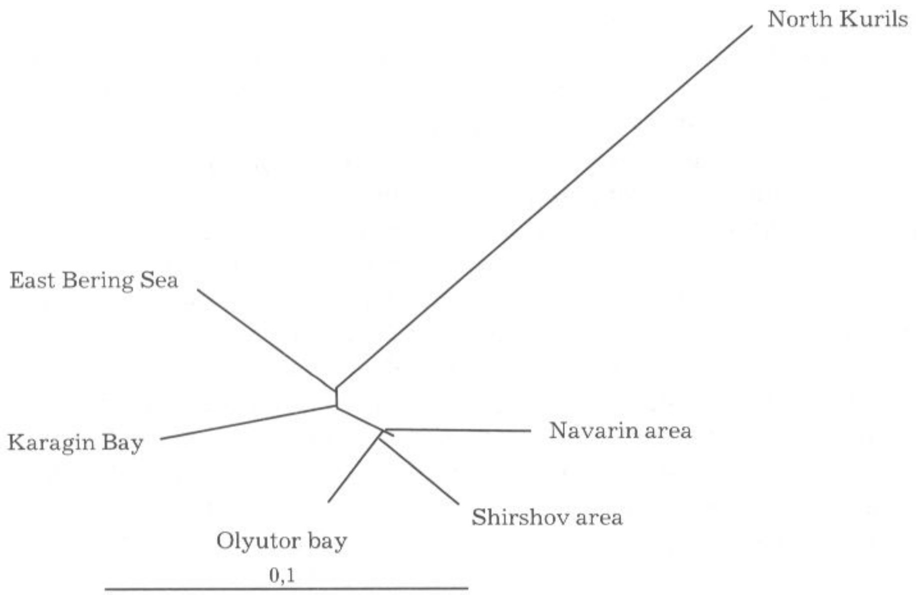

**Fig. 6.4.** Unrooted Nei genetic distance tree between various groupings of pollock

## Population structure

Over the entire period of studies of the Bering Sea pollock population structure, many scientists arrived at the conclusion that there was an independent population in the northern part of the sea (Serobaba, 1977; Moiseev, 1983; Hinkley, 1987; Low, 1989 /concerning pollock in waters northward of the Pribiloff Islands/; Varkentin, 1998; Datskij et al., 1999; Datskij, 2000; Balykin, Varkentin, 2002 a, etc.). However, such a conclusion was only drawn on the basis of one or two approaches to population studies; as a result, they were prone to scientific criticism. Analysis of results of complex repeated in a year seasonal surveys and application of virtually the whole set of approaches to population studies is the only tool which give possibility to identify population structure of the North Bering Sea pollock.

Summarizing the discussed material could establish the following. Specific bottom topography, hydrology, and climate peculiarities of the North Bering Sea, formed conditions in this area different from adjacent waters. Quasistationary eddies maintain a relative stability of the Navarin biotope. As a result, this region provides all-year-round favorable conditions for pollock at all stages of ontogenesis, from embryos to mature fish. The inflow of the Navarin current to the shelf ensures transport of embryos and larvae to shallow waters, where the high level of survival is provided by favorable abiotic conditions (i.e. concentrations of embryos and larvae in areas with cycle currents) and biotic ones (i.e. upwelling of nutrient-rich bottom waters in cyclonic eddies with the subsequent development of ample forage resources). In years of low abundance, when intraspecific competition for space and food decreases, migration routes of the Navarin pollock are short. In periods of high abundance, migration activity increases and, as a result, during the feeding season the Southern area of Navarin region accommodates mixed stocks of pollock from various regions, primarily, from the northern, eastern and western parts of the sea. Dwelling in unique conditions of the Navarin region, pollock has developed unique biological features: time and area of spawning; age at maturation; length and direction of ontogenetic, feeding, wintering, and spawning migrations; distribution of feeding and wintering grounds. Analysis of genetic markers confirms isolation of the North Bering Sea (Navarin) pollock aggregations, which, despite recurrent mixing with its neighbors, has continued on its own obviously long enough to develop its heritable differentiations from specimen from other Bering Sea regions. Fulfillment of the Hardy-Weinberg equilibruim proves panmixic nature of the Navarin pollock. Nei distances between the Navarin pollock and the East Bering Sea stock calculated with the protein markers (from literature), mitochondrial markers (from literature), and microsatellite DNA (own data) correspond to the population level.

Consequently, in accordance with today's most common definitions of the term of «population», the North Bering Sea pollock grouping should be classified as an independent population (Glubokov, 2005).

A pronounced flow of migrants between populations causes dissipation of their boundaries (Glubokovskiy, 1987). Indeed, the Navarin region accepts migrants from the East and West Bering Sea. The portion of such migrants vary considerably and depends on season and year. However, knowledge accumulated during the last decade shows that the migrant share is far less than it was considered earlier (Glubokov, Kotenev, 1999; Datskij, 2000; Balykin, Varkentin, 2002 a; Glubokov, Norvillo, 2002; Glubokov, 2003; Stepanenko, 2003; Bulatov, 2004; Glubokov, 2005).

The pollock population analysts often emphasize the population abundance and geographical distance between populations considering these two features criteria of independence. Such deliberations come to a thesis that small populations could not be independent. According population concept an essential prerequisite of a population existence is not the size, but stability on the spatial and temporal scales. The possibility of the long residence in particular habitat provides for the specific adaptations to a particular statio, while its differentiations and distinguishing features (physical or biological) as against neighbors maintain the intrapopulation panmixia. In spite of big size typical example of a «false» population is the pollock stock of the deepwater part of the Bering Sea. According to various estimates, the maximum biomass of deepwater aggregations attained 4—9 mln t of pollock (Sasaki, 1989; Dawson, 1989 b). If we consider the maximum values of biomass and the distribution area, deepwater Bering Sea pollock schools stand higher than the West Bering Sea independent population. With decrease in abundance of the Southeast Bering Sea pollock (particularly, the entire stock from the Bogoslof region which migrated to the enclave), pollock virtually disappeared from the Central Bering Sea. On the contrary, in the Navarin region pollock preserves its population structure and reproduction, when the neighbors' migrations become less intensive.

Given a complex hierarchic organization of the pollock population systems, a definite answer to the question about population status of all pollock aggregations in the Bering and Okhotsk seas and adjacent waters of the North Pacific shall not obtain in the coming decades. Nevertheless, analysis of publications and observations collected during the ten-year surveys allows to suggest that the level of distinction of the Navarin pollock from the West Bering Sea and the East Bering Sea populations by the entire set of the discussed characteristics corresponds to the level of distinction between the latter populations. In other words, if we refused to consider the Navarin grouping a population, we should unite all the Bering Sea populations into one hyperpopulation. And even in that case it should not be claimed that the Bering Sea pollock and that of the Sea of Okhotsk are fully isolated from each other. This was proved by results of Japanese experiments on tagging which showed two-way migrations between these two seas.

All the above said allowed us to develop a scheme of pollock population structure in the North Bering Sea and adjacent waters (Fig. 6.5) and show main pollock populations, bordering the Navarin one, and their range in periods of high abundance (hatched) and low abundance (areas of particularly dense aggregations – solid blue). Direction of migrations is indicated by arrows. Migration routes which are not prominent today are shown by dotted arrows. It is quite clear on the scheme that there are regions in the Bering Sea where pollock from three populations (the East Bering Sea, Navarin, and West Bering Sea) mix together. Naturally, it is very difficult to differentiate the origin of the mixed pollock especially in periods of high abundance.

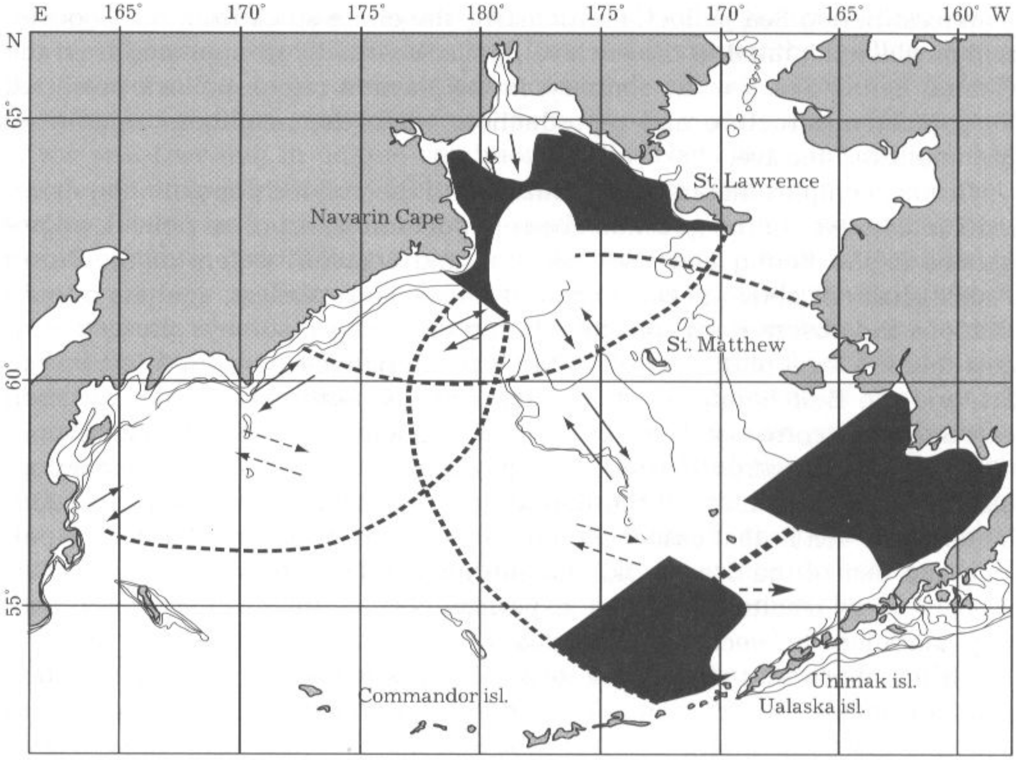

**Fig. 6.5.** Scheme of pollock population structure in the North Bering Sea and adjacent waters: – nucleus; ⟶ – main migration routes; - - ➤ – migration routes in periods of high abundance; ----- – population range in periods of high abundance

# CHAPTER 7

# FISHERY MANAGEMENT OF THE NORTH BERING SEA POLLOCK

Classification of the Navarin pollock population as an independent one makes it reasonable to assess the stock and develop specific fishery management for this population different from that applied to the neighboring populations.

## Direct estimation technique

We refused to perform a retrospective estimation of the Navarin pollock biomass because in the absence of sufficient data, such assessment would have been generally based on sufficient assumptions, which would have made it uncertain and almost useless in studies of the biomass dynamics in past. Figure 7.1 reflects the Navarin pollock biomass calculated on the base of acoustic and bottom trawl surveys data using the spline-approximation method.

During the period of 1996—2003, the maximum biomass of the Navarin pollock (2,080,000 t) was recorded in July—August, 1996, while the minimum one (≈570,000 t) was observed in 2000. Since 2000, the biomass had been increasing yearly to attain 1,833,000 t by 2003.

Decrease in the Navarin pollock biomass at the turn of the century was associated with significant changes in the climate/oceanic factors and the fishery pressing (Glubokov, Kotenev, 1999; Hen, 1999; Radchenko et al., 2001; Glubokov, 2003).

## Model approach

Assessment of the Navarin pollock stock was made with the following data: the age composition of catches; catch per unit effort for the middle- and big-sized vessels; and results of trawl surveys of younger age groups (age 0+, 1+, and 2+). Abundance of younger age groups was considered in the stock

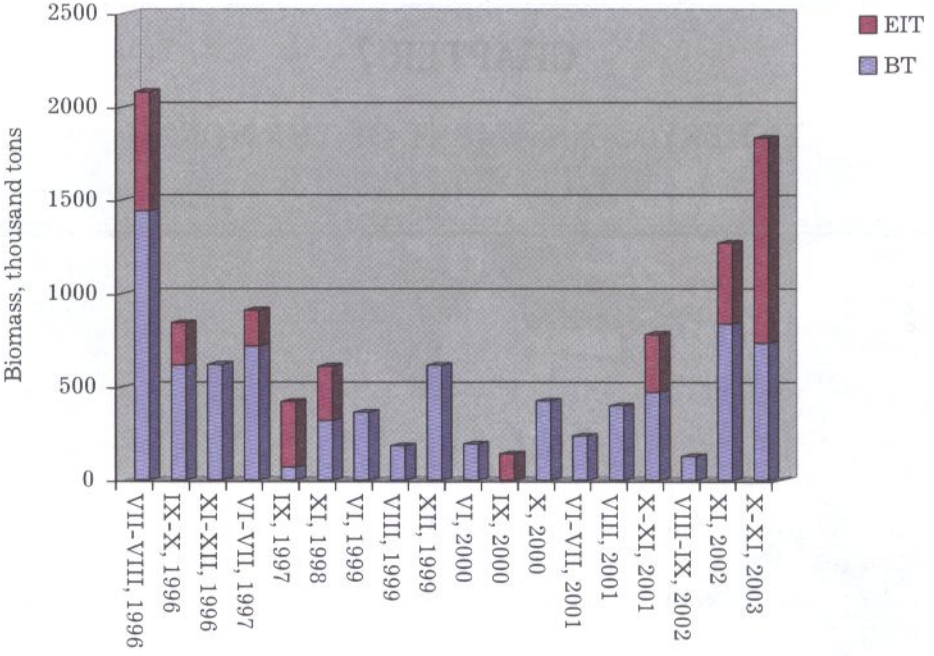

**Fig. 7.1.** Pollock biomass in Navarin region of the Bering Sea, for area of 14658 mile$^2$ (catchability rate – 1.0). EIT – Echointegration trawl survey; BT – Bottom trawl survey

assessment procedure both as an abundance indicator within the age structure, and as a relative proxy (number of recorded yearlings) of the spawning stock biomass.

The pollock stock was assessed with a cohort separable model of the ISVPA group (Vasil'ev, 2001; Vasilyev, 2001). The peculiarity of this group of models is the purposeful use of robustness principles in assessment of parameters, which decreases the impact of erroneous data on analytical results and allows fully extracts information about the examined system of «stock-fishery» from available data. Depending on characteristics and type of approximated by model data, components of the model target function were either a sum of lognormal remainders (data on the age composition in catches; catches per unit effort as an indicator of the fish stock biomass; and results of the 0+ age group survey as an indicator of the spawning stock biomass), or and absolute median deviation (AMD), i.e. a median of distribution of absolute deviations of lognormal remainders from their median value (data from surveys of the younger age groups).

Figure 7.2 illustrates profiles of components of the model target function. The minimum values indicate the most probable estimate of the effort */f(2005)/* in the separable presentation of the fishing mortality coefficients for the year of 2005. Profiles were obtained using each sort of information individually, as well as the entire set of the available information. To avoid a misunderstanding we should note that model parameter «fishing effort» is not numerically equal to the instant coefficient of fishing mortality; it is converted with age-dependent model assessment of the fishing selectivity. Virtually all the used data present similar information about the current state of the stock (Fig. 7.2). Naturally there is a moderate spread in values obtained with each sort of information.

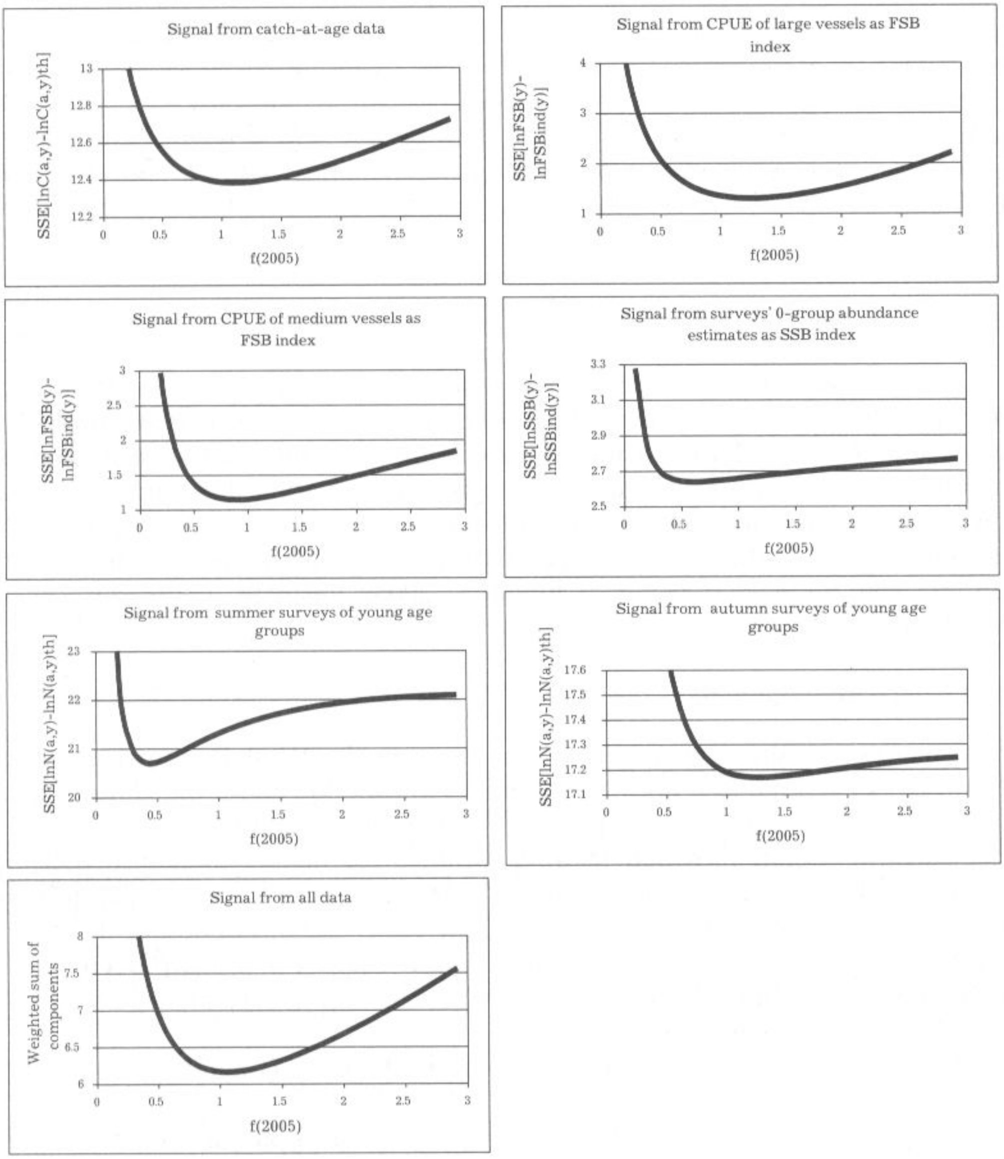

**Fig. 7.2.** Profiles of model target function components relative to various types of data

Use of the entire set of available information in the arbitrary bootstrapping of variables resulted in a moderate uncertainty in the stock biomass assessments (Fig. 7.3), which reflects a sufficient reliability of estimates (Vasilyev, Glubokov, 2005).

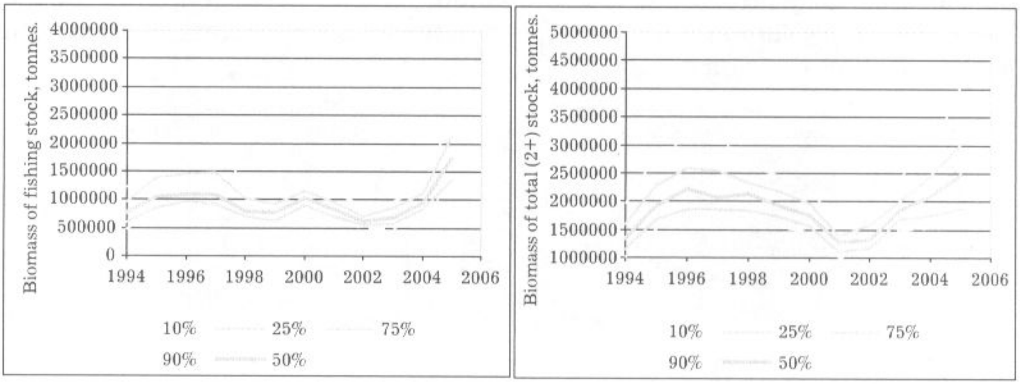

**Fig. 7.3.** Bootstrap distribution of estimated total and fish stock biomass of Navarin pollock

The biomass values yielded by cohort separable models of the ISVPA group are close to estimates based on data of echointegration and bottom trawl surveys (Fig. 7.1). Similarity in the biomass estimates and coherence in signals about the stock state from almost all sorts of observation data and from data on the age composition in catches indicate insignificant impact of the pollock migrations from other areas of the Bering Sea on abundance of the North Bering Sea pollock (Vasil'ev, Glubokov, 2005; Vasilyev, Glubokov, 2005; Vasilyev et al., 2005).

### Fishery management

Changes in fishery management practices in the West Bering Sea waters could be considered as a mirror of scientific knowledge about the Navarin pollock. In the late 1990s, according the dominating in that time perception that the Navarin region provided feeding grounds for mainly immature pollock from the East Bering Sea population, in 1994 fishing size limit for Navarin pollock was removal. Fishing for juveniles (in 1994—2000, pollock of 35 cm in length made 70—85% of commercial catches) resulted in a sharp decrease in pollock biomass. In order to reduce juvenile fishing, fishery managers had to establish the following measures:

— in June 1998, the minimum mesh size in the trawl codend was increased from 60 to 110 mm;

— in January 2000, the pollock fishing size limit of 30 cm was restored in the West Bering Sea;

– in December 2000, based on advanced scientific data on the pollock maturation rates the fishing size limit was increased up to 35 cm.

The established measures led to reduction in juvenile catches. Recruitment surveys made within the framework of the joint research project by VNIRO and the Far East Fishery Research institutes showed that before the fishing size limit was restored abundance of the 1998 year-class of the Navarin pollock declined 6.46 times from age of 2+ to 3+. After restoration of this measure abundance of the 1999 year-class of the same age and period only declined 1.58 times (Glubokov, 2003). Estimates of the fishery relative selectivity dependence on age obtained with a cohort separable model confirmed a considerable decrease in fishery pressure on younger age groups resulting from establishment of new fishing rules in 2000. Thus, in 1984 – 2000, the maximum fishing mortality characterized pollock at age 3 – 4, however, in 2001 – 2004, the main fishery pressure shifted to the five-year-old individuals (Fig. 7.4) (Vasil'ev, Glubokov, 2005).

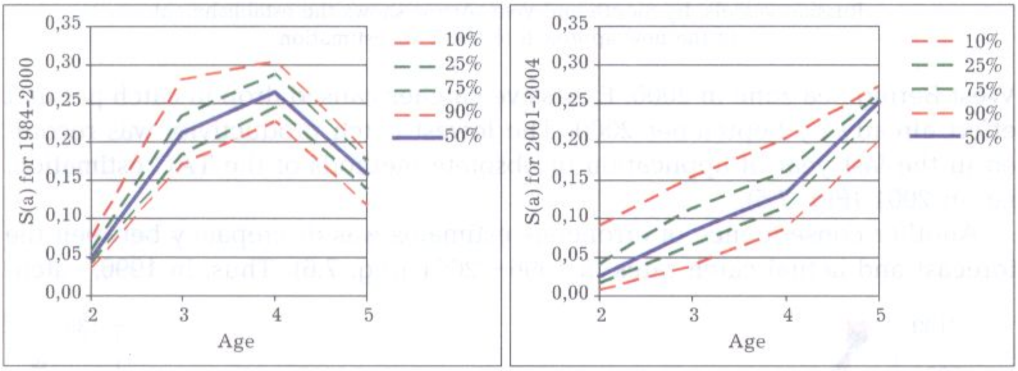

**Fig. 7.4.** Bootstrap distribution of relative fishery selectivity estimates (sum per unit) for younger age groups

Additionally, in 2000, a target fishing for pollock was closed in the West Bering Sea zone and in the Karagin subzone of the East Kamchatka zone during the spawning period (March 1 – April 20); in 2002, this closure in the West Bering Sea was extended till May 15. As a result, having finished the pollock fishing season in the Sea of Okhotsk in late April, neither large-sized fishing vessels (about 120 vessels), nor the medium-sized ones could not (as before) start to fish for the Navarin pollock. The later beginning of the fishing season as well as the Navarin stock abundance growth (due to favorable changes in climate/oceanic factors) led to increase in catches per unit effort in June – July 2000, compared to the previous year (Fig. 7.5). However, the northern pollock biomass and TAC were still estimated as a share of the respective values for the East Bering Sea population which were very high then. All this brought about overestimation pollock TAC (823,000 t) of the

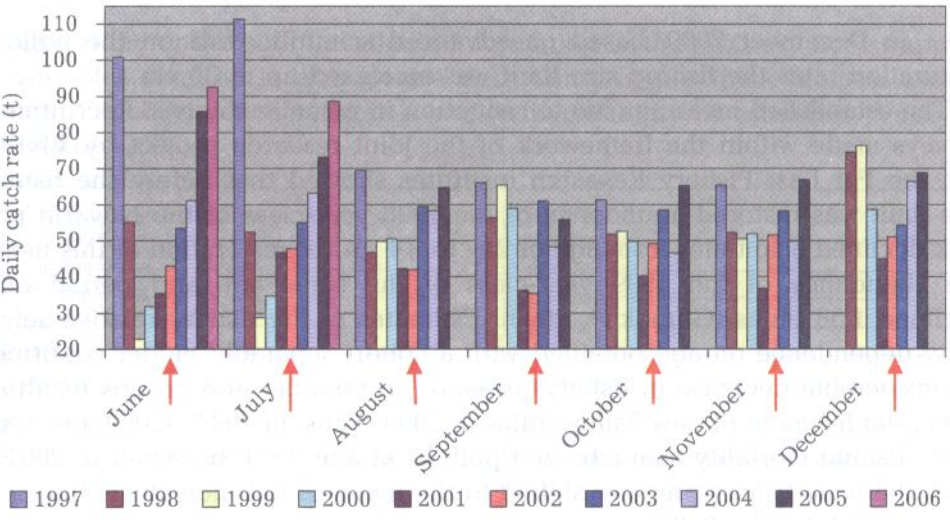

**Fig. 7.5.** Daily catch rate in pollock fishery in the West Bering Sea zone for large Russian vessels, by month and year. Arrow shows the establishment of the new approach to the TAC estimation

West Bering Sea zone in 2000. Excessive catches caused drop in catch per unit effort already by September 2000. The lowest catch productivity was recorded in the last year of application of obsolete methods of the TAC estimation, i.e. in 2001 (Fig. 7.5).

Another consequence of erroneous estimates was discrepancy between the forecast and actual catch rates in 1996 – 2001 (Fig. 7.6). Thus, in 1996, catch-

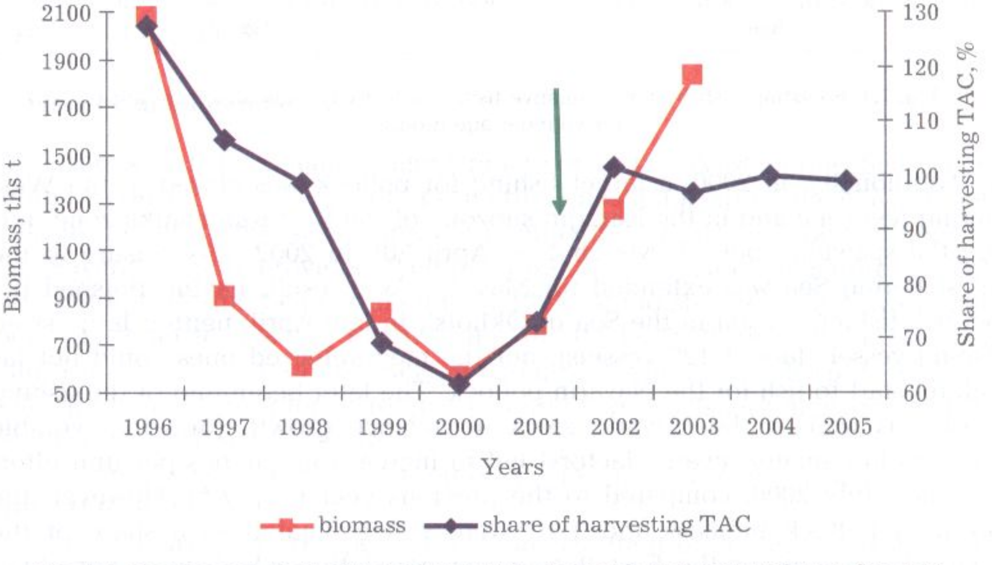

**Fig. 7.6.** Biomass and share of harvesting TAC of pollock in the West Bering Sea zone. Arrow shows the establishment of the new approach to the TAC estimation

es of pollock in the West Bering Sea zone made 127.6 % of TAC, while in 2000, this portion was only 61.6 %.

The Navarin pollock TAC was only set with consideration of actual state of the stock in 2002 and totaled 365,000 t.

Introduction of conservation and management measures based on perception that the North Bering Sea accommodated an independent population led to a rapid restoration of the stock, yearly increase in catch per unit effort and an appropriate correlation of actual and forecasted catches (Fig. 7.5, 7.6).

All the above mentioned results of implementation of the new approach to the Navarin pollock state forecasting provide additional evidence that this approach is the best fit for the population structure of the North Bering Sea pollock.

# CONCLUSION

This study based on the VNIRO original methodology, which was tested in the ten-year comprehensive studies and based on numerous literature data, confirms effectiveness of the developed techniques in examination of the population structure of marine fish species. The discussion in this book is mainly focused on the North Bering Sea (Navarin) pollock. Meanwhile some questiones of the pollock population structure in other regions of the Bering Sea and adjacent waters require further studies.

As it was already mentioned, Bristol Bay (the Bering Sea) and waters off the Southwest Kamchatka (the Sea of Okhotsk) accommodate biotopes similar to that in the Navarin region: their shelves have inflow of water masses directed to the northeast and quasistationary eddies, which create favorable conditions for formation of specific biocenoses. As a result, these three regions have developed high productivity zones where pollock aggregations attain the maximum biomass in the entire distribution area of the species. We have proven the independent population status of the Navarin pollock. As to the West Kamchatka and Unimak-Bristol pollock groupings, there is no unanimity on their population status.

Structure of the north part of the East Bering Sea pollock population is unclear too. According to our few survey data and literature data, some features of pollock from the St.Matthew, Pribiloff, and Unimak-Bristol regions vary. The fact that in the Unimak-Bristol and Pribiloff regions there are temporally stable schools and isolated spawning grounds allows to suggest that the southeast waters accommodate two independent populations. Clarification of the pollock reproduction peculiarities in the St.Matthew region requires annual repeated ichthyoplankton surveys. Results of these surveys as well as detailed genetic studies would elucidate the East Bering Sea pollock population structure.

At present there are still a lot of questions about population status of pollock in the Koryak region, which has stable spawning grounds (however, spawning does not annual), and, the Koryak pollock differs from the Navarin one in several features. Having isolated spawning grounds, the Koryak pollock, nevertheless, is similar to the West Bering Sea stock (Olyutor and Karagin bays) in many biological features. Our genetic studies conducted with assistance of E.A.Shubina and B.M.Mednikov (the Belozerskyi' Research Institute of physical-chemical Biology in the Moscow State University) indicated that the Koryak pollock belongs to the West Bering Sea population.

Thus, despite more than forty years of the Bering Sea pollock studies, there are a lot of gaps in our knowledge about its biology and population structure. The case of the Navarin pollock provides convincing evidence that erroneous perceptions about stock structure could cause their overexploitation, or, on the contrary, underexploitation. At present, due to objective or subjective causes, it is very difficult to organize and conduct such long-term comprehensive studies, as in case of the Navarin pollock. However, based on results of such studies the succeeding rational exploitation of a most productive pollock stock would obviously cover all the costs.

We hope that the methodology developed for studies of the North Bering Sea pollock aggregations would be applied not only in identification of the East Bering Sea and West Kamchatka pollock, but also populations of other marine fish species.

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**Appendix 1.1.** Cubic condition factor of the Bering Sea pollock, by area and age

| Year | Month | Pribiloff | | St.Matthew | | Navarin | | Koryak | | Olyutor | | Petropavlovsk-Kommandor | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | M* | m** | M | m | M | m | M | m | M | m | M | m |
| | | | | | | >10 years | | | | | | | |
| 1998 | XI–XII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.594 | 0.002 | n/a | n/a |
| 1999 | VI | n/a | n/a | n/a | n/a | 0.536 | 0.003 | 0.537 | 0.003 | 0.536 | 0.003 | n/a | n/a |
| | XII | n/a | n/a | n/a | n/a | 0.622 | 0.003 | 0.674 | 0.004 | n/a | n/a | n/a | n/a |
| 2000 | VII | n/a | n/a | n/a | n/a | 0.563 | 0.007 | 0.595 | 0.014 | 0.546 | 0.015 | n/a | n/a |
| 2001 | IV | n/a | n/a | n/a | n/a | 0.585 | 0.021 | n/a | n/a | n/a | n/a | n/a | n/a |
| | V | n/a | n/a | n/a | n/a | n/a | n/a | 0.583 | 0.013 | n/a | n/a | n/a | n/a |
| | VI | n/a | n/a | n/a | n/a | 0.557 | 0.005 | n/a | n/a | n/a | n/a | n/a | n/a |
| | VII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.563 | 0.024 | n/a | n/a |
| | VIII | n/a | n/a | n/a | n/a | 0.588 | 0.011 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2002 | IV | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.597 | 0.005 | n/a | n/a |
| 2003 | X–XI | n/a | n/a | n/a | n/a | 0.632 | 0.007 | n/a | n/a | n/a | n/a | n/a | n/a |
| | XI | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.637 | 0.035 | n/a | n/a |
| 2004 | II | n/a | n/a | n/a | n/a | 0.599 | 0.009 | n/a | n/a | n/a | n/a | n/a | n/a |
| | | | | | | 5–10 years | | | | | | | |
| 1998 | XI | n/a | n/a | n/a | n/a | 0.619 | 0.003 | n/a | n/a | n/a | n/a | n/a | n/a |
| | XI–XII | n/a | n/a | n/a | n/a | n/a | n/a | 0.616 | 0.003 | 0.608 | 0.004 | n/a | n/a |
| 1999 | VI | n/a | n/a | n/a | n/a | 0.564 | 0.005 | 0.57 | 0.003 | 0.548 | 0.002 | n/a | n/a |
| | VII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.578 | 0.003 | n/a | n/a |
| | XI–XII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.616 | 0.003 | n/a | n/a |
| | XII | n/a | n/a | n/a | n/a | 0.6 | 0.002 | 0.627 | 0.004 | n/a | n/a | n/a | n/a |
| 2000 | VII | n/a | n/a | n/a | n/a | 0.578 | 0.003 | 0.623 | 0.005 | 0.561 | 0.003 | n/a | n/a |
| | VIII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.613 | 0.004 | n/a | n/a |
| 2001 | IV | n/a | n/a | n/a | n/a | 0.557 | 0.01 | n/a | n/a | n/a | n/a | n/a | n/a |
| | V | n/a | n/a | n/a | n/a | n/a | n/a | 0.58 | 0.003 | n/a | n/a | n/a | n/a |

**Continuation Appendix 1.1**

| Year | Month | Pribiloff | | St.Matthew | | Navarin | | Koryak | | Olyutor | | Petropavlovsk-Kommandor | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | M* | m** | M | m | M | m | M | m | M | m | M | m |
| 2001 | VI | n/a | n/a | n/a | n/a | 0.576 | 0.003 | n/a | n/a | n/a | n/a | n/a | n/a |
| | VII | n/a | n/a | n/a | n/a | n/a | n/a | 0.616 | 0.004 | 0.582 | 0.005 | n/a | n/a |
| | VIII | n/a | n/a | n/a | n/a | 0.579 | 0.004 | 0.658 | 0.006 | 0.619 | 0.003 | n/a | n/a |
| 2002 | IV | n/a | n/a | n/a | n/a | n/a | n/a | 0.62 | 0.007 | 0.586 | 0.003 | n/a | n/a |
| 2003 | X – XI | n/a | n/a | n/a | n/a | 0.617 | 0.002 | n/a | n/a | n/a | n/a | n/a | n/a |
| | XI | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.603 | 0.005 | 0.601 | 0.005 |
| 2004 | II | n/a | n/a | n/a | n/a | 0.65 | 0.011 | n/a | n/a | n/a | n/a | n/a | n/a |
| | VII | 0.59 | 0.006 | 0.592 | 0.006 | 0.583 | 0.006 | n/a | n/a | n/a | n/a | n/a | n/a |
| | | | | | | 4+ | | | | | | | |
| 1998 | XI – XII | n/a | n/a | n/a | n/a | n/a | n/a | 0.622 | 0.003 | 0.65 | 0.003 | n/a | n/a |
| 1999 | VI | n/a | n/a | n/a | n/a | 0.559 | 0.005 | 0.564 | 0.004 | 0.554 | 0.004 | n/a | n/a |
| | XI – XII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.625 | 0.004 | n/a | n/a |
| | XII | n/a | n/a | n/a | n/a | 0.609 | 0.005 | 0.636 | 0.003 | n/a | n/a | n/a | n/a |
| 2000 | VII | n/a | n/a | n/a | n/a | 0.572 | 0.008 | n/a | n/a | 0.57 | 0.005 | n/a | n/a |
| 2001 | IV | n/a | n/a | n/a | n/a | 0.533 | 0.016 | n/a | n/a | n/a | n/a | n/a | n/a |
| | V | n/a | n/a | n/a | n/a | n/a | n/a | 0.555 | 0.004 | n/a | n/a | n/a | n/a |
| | VI | n/a | n/a | n/a | n/a | 0.547 | 0.006 | n/a | n/a | n/a | n/a | n/a | n/a |
| | VII | n/a | n/a | n/a | n/a | n/a | n/a | 0.62 | 0.007 | 0.578 | 0.005 | n/a | n/a |
| | VIII | n/a | n/a | n/a | n/a | 0.598 | 0.005 | 0.688 | 0.008 | 0.638 | 0.009 | n/a | n/a |
| 2002 | IV | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.585 | 0.005 | n/a | n/a |
| 2003 | X – XI | n/a | n/a | n/a | n/a | 0.628 | 0.005 | n/a | n/a | n/a | n/a | n/a | n/a |
| | XI | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.597 | 0.004 | 0.623 | 0.005 |
| 2004 | VII | 0.613 | 0.006 | 0.61 | 0.004 | 0.604 | 0.003 | n/a | n/a | n/a | n/a | n/a | n/a |
| | | | | | | 3+ | | | | | | | |
| 1999 | VI | n/a | n/a | n/a | n/a | 0.516 | 0.004 | n/a | n/a | 0.532 | 0.005 | n/a | n/a |
| | XI – XII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.618 | 0.003 | n/a | n/a |

**Continuation Appendix 1.1**

| Year | Month | Pribiloff | | St.Matthew | | Navarin | | Koryak | | Olyutor | | Petropavlovsk-Kommandor | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | M* | m** | M | m | M | m | M | m | M | m | M | m |
| 1999 | XII | n/a | n/a | n/a | n/a | 0.606 | 0.005 | 0.62 | 0.004 | n/a | n/a | n/a | n/a |
| 2000 | VI | n/a | n/a | n/a | n/a | 0.546 | 0.006 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2001 | V | n/a | n/a | n/a | n/a | n/a | n/a | 0.548 | 0.013 | n/a | n/a | n/a | n/a |
| | VI | n/a | n/a | n/a | n/a | 0.546 | 0.01 | n/a | n/a | n/a | n/a | n/a | n/a |
| | VII | n/a | n/a | n/a | n/a | n/a | n/a | 0.644 | 0.006 | n/a | n/a | n/a | n/a |
| | VIII | n/a | n/a | n/a | n/a | 0.599 | 0.013 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2003 | X–XI | n/a | n/a | n/a | n/a | 0.633 | 0.006 | n/a | n/a | n/a | n/a | n/a | n/a |
| | XI | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.593 | 0.003 | n/a | n/a |
| 2004 | VII | 0.623 | 0.01 | 0.622 | 0.009 | 0.614 | 0.004 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2+ | | | | | | | | | | | | | |
| 1999 | VI | n/a | n/a | n/a | n/a | 0.497 | 0.006 | n/a | n/a | n/a | n/a | n/a | n/a |
| | XII | n/a | n/a | n/a | n/a | 0.594 | 0.005 | 0.621 | 0.006 | n/a | n/a | n/a | n/a |
| 2000 | VI | n/a | n/a | n/a | n/a | 0.503 | 0.007 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2001 | V | n/a | n/a | n/a | n/a | n/a | n/a | 0.559 | 0.029 | n/a | n/a | n/a | n/a |
| | VI | n/a | n/a | n/a | n/a | 0.544 | 0.005 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2003 | X–XI | n/a | n/a | n/a | n/a | 0.635 | 0.007 | n/a | n/a | n/a | n/a | n/a | n/a |
| | XI | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.586 | 0.003 | n/a | n/a |
| 2004 | VII | 0.556 | n/a | 0.574 | 0.014 | 0.602 | 0.007 | n/a | n/a | n/a | n/a | n/a | n/a |
| 1+ | | | | | | | | | | | | | |
| 1999 | XII | n/a | n/a | n/a | n/a | 0.546 | 0.007 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2000 | VI | n/a | n/a | n/a | n/a | 0.487 | 0.009 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2001 | VI | n/a | n/a | n/a | n/a | 0.499 | 0.008 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2003 | X–XI | n/a | n/a | n/a | n/a | 0.593 | 0.009 | n/a | n/a | n/a | n/a | n/a | n/a |
| | XI | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.582 | 0.026 | n/a | n/a |
| 2004 | VII | n/a | n/a | 0.585 | 0.007 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| 0+ | | | | | | | | | | | | | |
| 2003 | X–XI | n/a | n/a | n/a | n/a | 0.554 | 0.014 | n/a | n/a | n/a | n/a | n/a | n/a |

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Note: * – arithmetic mean;

** – mean error

**Appendix 1.2.** Gonadosomatic index of the Bering Sea female pollock, by area and age (notation as in 1.1.)

| Year | Month | Pribiloff | | St.Matthew | | Navarin | | Koryak | | Olyutor | | Petropavlovsk-Kommandor | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | M | m | M | m | M | m | M | m | M | m | M | m |
| >10 years | | | | | | | | | | | | | |
| 1998 | VII | n/a | n/a | n/a | n/a | 3.02 | 0.26 | n/a | n/a | n/a | n/a | n/a | n/a |
| | VIII | n/a | n/a | n/a | n/a | n/a | n/a | 1.83 | 0.24 | n/a | n/a | n/a | n/a |
| | XI – XII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 5.51 | 1.09 | n/a | n/a |
| 1999 | VI | n/a | n/a | n/a | n/a | 4.49 | 0.31 | 5.08 | 1.35 | 4.07 | 1.25 | n/a | n/a |
| | XII | n/a | n/a | n/a | n/a | 4.76 | 0.54 | 10.05 | 5.46 | n/a | n/a | n/a | n/a |
| 2000 | VII | n/a | n/a | n/a | n/a | 4.04 | 0.63 | 2.87 | 0.49 | 3.56 | 0.89 | n/a | n/a |
| 2001 | IV | n/a | n/a | n/a | n/a | 12.47 | 3.19 | n/a | n/a | n/a | n/a | n/a | n/a |
| | V | n/a | n/a | n/a | n/a | n/a | n/a | 8.93 | 2.04 | n/a | n/a | n/a | n/a |
| | VI | n/a | n/a | n/a | n/a | 4.6 | 0.29 | n/a | n/a | n/a | n/a | n/a | n/a |
| | VII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 6.83 | 2.54 | n/a | n/a |
| | VIII | n/a | n/a | n/a | n/a | 5.16 | 1.03 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2002 | IV | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 21.07 | 0.91 | n/a | n/a |
| 2003 | X – XI | n/a | n/a | n/a | n/a | 7.4 | 0.64 | n/a | n/a | n/a | n/a | n/a | n/a |
| | XI | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 4.35 | 0.33 | n/a | n/a |
| 2004 | II | n/a | n/a | n/a | n/a | 11.31 | 0.82 | n/a | n/a | n/a | n/a | n/a | n/a |
| 5 – 10 years | | | | | | | | | | | | | |
| 1998 | VI | n/a | n/a | n/a | n/a | 2.24 | 0.3 | n/a | n/a | 2.37 | 0.19 | n/a | n/a |
| | VII | n/a | n/a | n/a | n/a | 1.83 | 0.06 | n/a | n/a | 2.29 | 0.23 | n/a | n/a |
| | VIII | n/a | n/a | n/a | n/a | n/a | n/a | 2.38 | 0.37 | 2.05 | 0.08 | n/a | n/a |
| | IX | n/a | n/a | n/a | n/a | 2 | 0.18 | 1.83 | 0.11 | n/a | n/a | n/a | n/a |
| | X | n/a | n/a | n/a | n/a | n/a | n/a | 1.99 | 0.007 | 2.52 | 0.06 | n/a | n/a |
| | XI | n/a | n/a | n/a | n/a | 3.28 | 0.15 | n/a | n/a | n/a | n/a | n/a | n/a |
| | XI – XII | n/a | n/a | n/a | n/a | n/a | n/a | 3.61 | 0.23 | 3.61 | 0.13 | n/a | n/a |
| 1999 | VI | n/a | n/a | n/a | n/a | 2.98 | 0.26 | 2.68 | 0.3 | 2.52 | 0.17 | n/a | n/a |
| | VII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 2.23 | 0.16 | n/a | n/a |
| | XI – XII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 2.98 | 0.88 | n/a | n/a |

**Continuation Appendix 1.2**

| Year | Month | Pribiloff | | St.Matthew | | Navarin | | Koryak | | Olyutor | | Petropavlovsk-Kommandor | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | M | m | M | m | M | m | M | m | M | m | M | m |
| 1999 | XII | n/a | n/a | n/a | n/a | 3.85 | 0.22 | 3.02 | 0.28 | n/a | n/a | n/a | n/a |
| 2000 | VII | n/a | n/a | n/a | n/a | 2.41 | 0.13 | 2.04 | 0.16 | 2.2 | 0.1 | n/a | n/a |
| | VIII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 2.11 | 0.11 | n/a | n/a |
| 2001 | IV | n/a | n/a | n/a | n/a | 3.54 | 0.6 | n/a | n/a | n/a | n/a | n/a | n/a |
| | V | n/a | n/a | n/a | n/a | n/a | n/a | 2.1 | 0.19 | n/a | n/a | n/a | n/a |
| | VI | n/a | n/a | n/a | n/a | 2.53 | 0.12 | n/a | n/a | n/a | n/a | n/a | n/a |
| | VII | n/a | n/a | n/a | n/a | n/a | n/a | 2.02 | 0.21 | 2.49 | 0.31 | n/a | n/a |
| | VIII | n/a | n/a | n/a | n/a | 2.22 | 0.15 | 2.38 | 0.35 | 1.61 | 0.06 | n/a | n/a |
| 2002 | IV | n/a | n/a | n/a | n/a | n/a | n/a | 14.5 | 0.17 | 12.98 | 0.68 | n/a | n/a |
| 2003 | X – XI | n/a | n/a | n/a | n/a | 4.22 | 0.18 | n/a | n/a | n/a | n/a | n/a | n/a |
| | XI | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 3.48 | 0.3 | 7.36 | 0.78 |
| 2004 | II | n/a | n/a | n/a | n/a | 12.05 | 0.93 | n/a | n/a | n/a | n/a | n/a | n/a |
| | VII | 3 | 0.48 | 2.43 | 0.23 | 1.77 | 0.13 | n/a | n/a | n/a | n/a | n/a | n/a |
| 4+ | | | | | | | | | | | | | |
| 1998 | VI | n/a | n/a | n/a | n/a | 1.01 | 0.11 | n/a | n/a | 1.29 | 0.15 | n/a | n/a |
| | VII | n/a | n/a | n/a | n/a | 1.4 | 0.15 | n/a | n/a | n/a | n/a | n/a | n/a |
| | VIII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 1.35 | 0.18 | n/a | n/a |
| | IX | n/a | n/a | n/a | n/a | 1.78 | 0.31 | 1.22 | 0.14 | n/a | n/a | n/a | n/a |
| | XI – XII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 1.84 | 0.2 | n/a | n/a |
| 1999 | VI | n/a | n/a | n/a | n/a | 0.88 | 0.08 | 0.89 | 0.12 | 0.68 | 0.08 | n/a | n/a |
| | XI – XII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 1.69 | 0.38 | n/a | n/a |
| | XII | n/a | n/a | n/a | n/a | 2.04 | 0.26 | 1.49 | 0.22 | n/a | n/a | n/a | n/a |
| 2000 | VII | n/a | n/a | n/a | n/a | 0.97 | 0.12 | n/a | n/a | 0.67 | 0.13 | n/a | n/a |
| 2001 | IV | n/a | n/a | n/a | n/a | 1.36 | 0.45 | n/a | n/a | n/a | n/a | n/a | n/a |
| | V | n/a | n/a | n/a | n/a | n/a | n/a | 0.92 | 0.07 | n/a | n/a | n/a | n/a |
| | VI | n/a | n/a | n/a | n/a | 1.2 | 0.16 | n/a | n/a | n/a | n/a | n/a | n/a |

**Continuation Appendix 1.2**

| Year | Month | Pribiloff | | St.Matthew | | Navarin | | Koryak | | Olyutor | | Petropavlovsk-Kommandor | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | M | m | M | m | M | m | M | m | M | m | M | m |
| 2001 | VII | n/a | n/a | n/a | n/a | n/a | n/a | 1.43 | 0.24 | 1.32 | 0.31 | n/a | n/a |
| | VIII | n/a | n/a | n/a | n/a | 1.5 | 0.17 | 1.79 | 0.59 | 1.34 | 0.09 | n/a | n/a |
| 2002 | IV | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.98 | 0.11 | n/a | n/a |
| 2003 | X – XI | n/a | n/a | n/a | n/a | 1.9 | 0.13 | n/a | n/a | n/a | n/a | n/a | n/a |
| | XI | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.82 | 0.06 | 2.91 | 0.57 |
| 2004 | VII | 1.74 | 0.21 | 1.55 | 0.11 | 1.24 | 0.1 | n/a | n/a | n/a | n/a | n/a | n/a |
| 3+ | | | | | | | | | | | | | |
| 1998 | VI | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.73 | 0.37 | n/a | n/a |
| 1999 | VI | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.44 | 0.14 | n/a | n/a |
| | XI – XII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.57 | 0.04 | n/a | n/a |
| | XII | n/a | n/a | n/a | n/a | 1.24 | 0.13 | 0.84 | 0.26 | n/a | n/a | n/a | n/a |
| 2000 | VI | n/a | n/a | n/a | n/a | 0.72 | 0.06 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2001 | V | n/a | n/a | n/a | n/a | n/a | n/a | 0.62 | 0.08 | n/a | n/a | n/a | n/a |
| | VI | n/a | n/a | n/a | n/a | 0.85 | 0.14 | n/a | n/a | n/a | n/a | n/a | n/a |
| | VII | n/a | n/a | n/a | n/a | n/a | n/a | 1.06 | 0.1 | n/a | n/a | n/a | n/a |
| | VIII | n/a | n/a | n/a | n/a | 0.98 | 0.2 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2003 | X – XI | n/a | n/a | n/a | n/a | 0.68 | 0.09 | n/a | n/a | n/a | n/a | n/a | n/a |
| | XI | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.57 | 0.02 | n/a | n/a |
| 2004 | VII | 1.22 | 0.13 | 0.8 | 0.07 | 0.74 | 0.05 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2+ | | | | | | | | | | | | | |
| 1999 | XII | n/a | n/a | n/a | n/a | 0.75 | 0.04 | 0.41 | 0.02 | n/a | n/a | n/a | n/a |
| 2000 | VI | n/a | n/a | n/a | n/a | 1.94 | 0.14 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2001 | V | n/a | n/a | n/a | n/a | n/a | n/a | 0.54 | 0.07 | n/a | n/a | n/a | n/a |
| | VI | n/a | n/a | n/a | n/a | 0.46 | 0.04 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2003 | X – XI | n/a | n/a | n/a | n/a | 0.38 | 0.02 | n/a | n/a | n/a | n/a | n/a | n/a |
| | XI | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.39 | 0.01 | n/a | n/a |
| 2004 | VII | 0.114 | n/a | n/a | n/a | 0.48 | 0.07 | n/a | n/a | n/a | n/a | n/a | n/a |
| 1+ | | | | | | | | | | | | | |
| 1999 | XII | n/a | n/a | n/a | n/a | 0.37 | 0.04 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2003 | XI | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.33 | 0.04 | n/a | n/a |
| 2004 | VII | n/a | n/a | 0.176 | 0.046 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |

**Appendix 1.3.** Gonadosomatic index of the Bering Sea male pollock, by area and age (notation as in 1.1.)

| Year | Month | Pribiloff | | St.Matthew | | Navarin | | Koryak | | Olyutor | | Petropavlovsk-Kommandor | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | M | m | M | m | M | m | M | m | M | m | M | m |
| | | | | | | >10 years | | | | | | | |
| 1999 | VI | n/a | n/a | n/a | n/a | 2.99 | 0.49 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2000 | VII | n/a | n/a | n/a | n/a | 3.02 | 0.42 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2001 | IV | n/a | n/a | n/a | n/a | 10.69 | 1.02 | n/a | n/a | n/a | n/a | n/a | n/a |
| | V | n/a | n/a | n/a | n/a | n/a | n/a | 5.61 | 2.17 | n/a | n/a | n/a | n/a |
| | VI | n/a | n/a | n/a | n/a | 2 | 0.4 | n/a | n/a | n/a | n/a | n/a | n/a |
| | VIII | n/a | n/a | n/a | n/a | 1.9 | 0.21 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2002 | IV | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 9.69 | 1.14 | n/a | n/a |
| 2003 | X–XI | n/a | n/a | n/a | n/a | 5.64 | 0.99 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2004 | II | n/a | n/a | n/a | n/a | 6.38 | 0.74 | n/a | n/a | n/a | n/a | n/a | n/a |
| | | | | | | 5–10 years | | | | | | | |
| 1998 | VI | n/a | n/a | n/a | n/a | 1.62 | 0.22 | n/a | n/a | 1.94 | 0.13 | n/a | n/a |
| | VII | n/a | n/a | n/a | n/a | 1.33 | 0.08 | n/a | n/a | 1.39 | 0.22 | n/a | n/a |
| | VIII | n/a | n/a | n/a | n/a | n/a | n/a | 1.22 | 0.31 | 1.02 | 0.06 | n/a | n/a |
| | IX | n/a | n/a | n/a | n/a | 2.05 | 0.36 | 1.03 | 0.09 | n/a | n/a | n/a | n/a |
| | X | n/a | n/a | n/a | n/a | n/a | n/a | 3.21 | 0.16 | 2.05 | 0.14 | n/a | n/a |
| | XI | n/a | n/a | n/a | n/a | 5.99 | 0.47 | n/a | n/a | n/a | n/a | n/a | n/a |
| | XI–XII | n/a | n/a | n/a | n/a | n/a | n/a | 5.94 | 0.57 | 6.29 | 0.38 | n/a | n/a |
| 1999 | VI | n/a | n/a | n/a | n/a | 1.89 | 0.22 | 1.63 | 0.23 | 1.76 | 0.37 | n/a | n/a |
| | VII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 1.65 | 0.17 | n/a | n/a |
| | XI–XII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 6.82 | 2.23 | n/a | n/a |
| | XII | n/a | n/a | n/a | n/a | 5.15 | 0.34 | 4.94 | 0.68 | n/a | n/a | n/a | n/a |
| 2000 | VII | n/a | n/a | n/a | n/a | 2.35 | 0.18 | 0.88 | 0.13 | 1.08 | 0.13 | n/a | n/a |
| | VIII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 1.37 | 0.17 | n/a | n/a |
| 2001 | IV | n/a | n/a | n/a | n/a | 3.62 | 1.25 | n/a | n/a | n/a | n/a | n/a | n/a |
| | V | n/a | n/a | n/a | n/a | n/a | n/a | 2.16 | 0.2 | n/a | n/a | n/a | n/a |
| | VI | n/a | n/a | n/a | n/a | 1.85 | 0.13 | n/a | n/a | n/a | n/a | n/a | n/a |
| | VII | n/a | n/a | n/a | n/a | n/a | n/a | 1.3 | 0.17 | 1.12 | 0.2 | n/a | n/a |

**Continuation Appendix 1.3**

| Year | Month | Pribiloff | | St.Matthew | | Navarin | | Koryak | | Olyutor | | Petropavlovsk-Kommandor | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | M | m | M | m | M | m | M | m | M | m | M | m |
| 2001 | VIII | n/a | n/a | n/a | n/a | 1.95 | 0.44 | 1.2 | 0.39 | 0.9 | 0.07 | n/a | n/a |
| 2002 | IV | n/a | n/a | n/a | n/a | n/a | n/a | 5.75 | 0.37 | 5.71 | 0.31 | n/a | n/a |
| 2003 | X – XI | n/a | n/a | n/a | n/a | 5.02 | 0.25 | n/a | n/a | n/a | n/a | n/a | n/a |
| | XI | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 5.84 | 0.31 | 9.55 | 0.41 |
| 2004 | II | n/a | n/a | n/a | n/a | 8.93 | 1.38 | n/a | n/a | n/a | n/a | n/a | n/a |
| | VII | 1.83 | 0.36 | 1.75 | 0.32 | 1.35 | 0.18 | n/a | n/a | n/a | n/a | n/a | n/a |
| 4+ | | | | | | | | | | | | | |
| 1998 | VI | n/a | n/a | n/a | n/a | 1.22 | 0.38 | n/a | n/a | 2.24 | 0.37 | n/a | n/a |
| | VII | n/a | n/a | n/a | n/a | 0.99 | 0.11 | n/a | n/a | n/a | n/a | n/a | n/a |
| | VIII | n/a | n/a | n/a | n/a | n/a | n/a | 0.57 | 0.22 | 0.78 | 0.1 | n/a | n/a |
| | IX | n/a | n/a | n/a | n/a | 1.12 | 0.23 | 0.98 | 0.36 | n/a | n/a | n/a | n/a |
| | X | n/a | n/a | n/a | n/a | n/a | n/a | 2.15 | 0.22 | n/a | n/a | n/a | n/a |
| | XI – XII | n/a | n/a | n/a | n/a | n/a | n/a | 6.44 | 1.82 | 4.15 | 0.46 | n/a | n/a |
| 1999 | VI | n/a | n/a | n/a | n/a | 2.1 | 0.24 | 1.44 | 0.31 | 1.25 | 0.24 | n/a | n/a |
| | XI – XII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 4.93 | 0.82 | n/a | n/a |
| | XII | n/a | n/a | n/a | n/a | 4.41 | 0.68 | 3.18 | 0.46 | n/a | n/a | n/a | n/a |
| 2000 | VII | n/a | n/a | n/a | n/a | 1.91 | 0.35 | n/a | n/a | 0.2 | 0.05 | n/a | n/a |
| 2001 | IV | n/a | n/a | n/a | n/a | 6.71 | 0.18 | n/a | n/a | n/a | n/a | n/a | n/a |
| | V | n/a | n/a | n/a | n/a | n/a | n/a | 0.8 | 0.15 | n/a | n/a | n/a | n/a |
| | VI | n/a | n/a | n/a | n/a | 1.03 | 0.27 | n/a | n/a | n/a | n/a | n/a | n/a |
| | VII | n/a | n/a | n/a | n/a | n/a | n/a | 1.21 | 0.32 | 0.66 | 0.18 | n/a | n/a |
| | VIII | n/a | n/a | n/a | n/a | 1.06 | 0.16 | 1.39 | 0.37 | 0.7 | 0.23 | n/a | n/a |
| 2002 | IV | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.69 | 0.26 | n/a | n/a |
| 2003 | X – XI | n/a | n/a | n/a | n/a | 2.89 | 0.39 | n/a | n/a | n/a | n/a | n/a | n/a |
| | XI | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 3.1 | 0.28 | 8.57 | 0.53 |
| 2004 | VII | 1.24 | 0.15 | 1.23 | 0.2 | 0.83 | 0.13 | n/a | n/a | n/a | n/a | n/a | n/a |

**Continuation Appendix 1.3**

| Year | Month | Pribiloff | | St.Matthew | | Navarin | | Koryak | | Olyutor | | Petropavlovsk-Kommandor | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | M | m | M | m | M | m | M | m | M | m | M | m |
| 3+ | | | | | | | | | | | | | |
| 1999 | VI | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.68 | 0.07 | n/a | n/a |
| | XI – XII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.97 | 0.19 | n/a | n/a |
| | XII | n/a | n/a | n/a | n/a | 0.97 | 0.19 | 0.37 | 0.08 | n/a | n/a | n/a | n/a |
| 2000 | VI | n/a | n/a | n/a | n/a | 0.66 | 0.15 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2001 | V | n/a | n/a | n/a | n/a | n/a | n/a | 1.88 | 0.12 | n/a | n/a | n/a | n/a |
| | VI | n/a | n/a | n/a | n/a | 0.85 | 0.14 | n/a | n/a | n/a | n/a | n/a | n/a |
| | VII | n/a | n/a | n/a | n/a | n/a | n/a | 0.4 | 0.13 | n/a | n/a | n/a | n/a |
| | VIII | n/a | n/a | n/a | n/a | 0.94 | 0.37 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2003 | X – XI | n/a | n/a | n/a | n/a | 0.8 | 0.28 | n/a | n/a | n/a | n/a | n/a | n/a |
| | XI | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.84 | 0.15 | n/a | n/a |
| 2004 | VII | 1.12 | 0.3 | 0.57 | 0.09 | 0.66 | 0.09 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2+ | | | | | | | | | | | | | |
| 1999 | XII | n/a | n/a | n/a | n/a | 0.39 | 0.57 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2000 | VI | n/a | n/a | n/a | n/a | 1.01 | 0.17 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2001 | VI | n/a | n/a | n/a | n/a | 0.36 | 0.16 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2003 | X – XI | n/a | n/a | n/a | n/a | 0.4 | 0.27 | n/a | n/a | n/a | n/a | n/a | n/a |
| | XI | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.39 | 0.09 | n/a | n/a |
| 2004 | VII | 0.4 | n/a | n/a | n/a | 0.28 | 0.03 | n/a | n/a | n/a | n/a | n/a | n/a |

**Appendix 1.4.** Hepatosomatic index of the Bering Sea female pollock, by area and age (notation as in 1.1.)

| Year | Month | Pribiloff |  | St.Matthew |  | Navarin |  | Koryak |  | Olyutor |  | Petropavlovsk-Kommandor |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  | M | m | M | m | M | m | M | m | M | m | M | m |
|  |  |  |  |  |  | >10 years |  |  |  |  |  |  |  |
| 1998 | VII | n/a | n/a | n/a | n/a | 6.3 | 0.26 | n/a | n/a | n/a | n/a | n/a | n/a |
|  | VIII | n/a | n/a | n/a | n/a | n/a | n/a | 7.92 | 1.29 | n/a | n/a | n/a | n/a |
|  | XI–XII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 12.08 | 1.32 | n/a | n/a |
| 1999 | VI | n/a | n/a | n/a | n/a | 5.75 | 0.19 | 5.94 | 0.58 | 7.35 | 1.12 | n/a | n/a |
|  | XII | n/a | n/a | n/a | n/a | 11.68 | 0.86 | 11.69 | 0.82 | n/a | n/a | n/a | n/a |
| 2000 | VII | n/a | n/a | n/a | n/a | 8.29 | 0.31 | 9.24 | 0.3 | 7.51 | 0.5 | n/a | n/a |
| 2001 | IV | n/a | n/a | n/a | n/a | 11.72 | 1.15 | n/a | n/a | n/a | n/a | n/a | n/a |
|  | V | n/a | n/a | n/a | n/a | n/a | n/a | 8.46 | 0.48 | n/a | n/a | n/a | n/a |
|  | VI | n/a | n/a | n/a | n/a | 8.54 | 0.19 | n/a | n/a | n/a | n/a | n/a | n/a |
|  | VII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 8.21 | 0.77 | n/a | n/a |
|  | VIII | n/a | n/a | n/a | n/a | 9.9 | 0.79 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2002 | IV | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 9.5 | 0.22 | n/a | n/a |
| 2003 | X–XI | n/a | n/a | n/a | n/a | 8.96 | 0.38 | n/a | n/a | n/a | n/a | n/a | n/a |
|  | XI | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 9.57 | 1.12 | n/a | n/a |
| 2004 | II | n/a | n/a | n/a | n/a | 7.86 | 0.33 | n/a | n/a | n/a | n/a | n/a | n/a |
|  |  |  |  |  |  | 5–10 years |  |  |  |  |  |  |  |
| 1998 | VI | n/a | n/a | n/a | n/a | 5.36 | 0.46 | n/a | n/a | 7.05 | 0.1 | n/a | n/a |
|  | VII | n/a | n/a | n/a | n/a | 5.75 | 0.16 | n/a | n/a | 7.54 | 0.26 | n/a | n/a |
|  | VIII | n/a | n/a | n/a | n/a | n/a | n/a | 7.33 | 0.17 | 8.93 | 0.12 | n/a | n/a |
|  | IX | n/a | n/a | n/a | n/a | 9.83 | 0.24 | 9.89 | 0.23 | n/a | n/a | n/a | n/a |
|  | X | n/a | n/a | n/a | n/a | n/a | n/a | 9.23 | 0.32 | 8.66 | 0.15 | n/a | n/a |
|  | XI | n/a | n/a | n/a | n/a | 9.54 | 0.3 | n/a | n/a | n/a | n/a | n/a | n/a |
|  | XI–XII | n/a | n/a | n/a | n/a | n/a | n/a | 8.57 | 0.38 | 9.15 | 0.14 | n/a | n/a |
| 1999 | VI | n/a | n/a | n/a | n/a | 5.13 | 0.16 | 6.17 | 0.16 | 5.92 | 0.14 | n/a | n/a |
|  | VII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 10.77 | 0.33 | n/a | n/a |
|  | XI–XII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 10.86 | 0.72 | n/a | n/a |
|  | XII | n/a | n/a | n/a | n/a | 10.47 | 0.24 | 11.6 | 0.51 | n/a | n/a | n/a | n/a |

**Continuation Appendix 1.4**

| Year | Month | Pribiloff | | St.Matthew | | Navarin | | Koryak | | Olyutor | | Petropavlovsk-Kommandor | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | M | m | M | m | M | m | M | m | M | m | M | m |
| 2000 | VII | n/a | n/a | n/a | n/a | 7.86 | 0.18 | 9.36 | 0.2 | 8.86 | 0.28 | n/a | n/a |
| | VIII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 10.22 | 0.16 | n/a | n/a |
| 2001 | IV | n/a | n/a | n/a | n/a | 7.16 | 0.3 | n/a | n/a | n/a | n/a | n/a | n/a |
| | V | n/a | n/a | n/a | n/a | n/a | n/a | 5.7 | 0.16 | n/a | n/a | n/a | n/a |
| | VI | n/a | n/a | n/a | n/a | 6.65 | 0.13 | n/a | n/a | n/a | n/a | n/a | n/a |
| | VII | n/a | n/a | n/a | n/a | n/a | n/a | 8.52 | 0.2 | 8.67 | 0.25 | n/a | n/a |
| | VIII | n/a | n/a | n/a | n/a | 6.94 | 0.29 | 10.9 | 0.29 | 10.46 | 0.18 | n/a | n/a |
| 2002 | IV | n/a | n/a | n/a | n/a | n/a | n/a | 8.22 | 0.51 | 6.99 | 0.15 | n/a | n/a |
| 2003 | X–XI | n/a | n/a | n/a | n/a | 7.76 | 0.15 | n/a | n/a | n/a | n/a | n/a | n/a |
| | XI | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 7.75 | 0.21 | 10.49 | 0.31 |
| 2004 | II | n/a | n/a | n/a | n/a | 8.96 | 0.46 | n/a | n/a | n/a | n/a | n/a | n/a |
| | VII | 6.49 | 0.47 | 7.55 | 0.31 | 7.85 | 0.29 | n/a | n/a | n/a | n/a | n/a | n/a |
| 4+ | | | | | | | | | | | | | |
| 1998 | VI | n/a | n/a | n/a | n/a | 5.12 | 0.51 | n/a | n/a | 7.73 | 0.33 | n/a | n/a |
| | VII | n/a | n/a | n/a | n/a | 5.94 | 0.27 | n/a | n/a | n/a | n/a | n/a | n/a |
| | VIII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 9.88 | 0.48 | n/a | n/a |
| | IX | n/a | n/a | n/a | n/a | 9.76 | 0.71 | 9.74 | 0.77 | n/a | n/a | n/a | n/a |
| | XI–XII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 8.94 | 0.46 | n/a | n/a |
| 1999 | VI | n/a | n/a | n/a | n/a | 4 | 0.73 | 5.87 | 0.56 | 6.7 | 0.39 | n/a | n/a |
| | XI–XII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 11.28 | 0.52 | n/a | n/a |
| | XII | n/a | n/a | n/a | n/a | 8.73 | 0.39 | 11.58 | 0.4 | n/a | n/a | n/a | n/a |
| 2000 | VII | n/a | n/a | n/a | n/a | 6.81 | 0.43 | n/a | n/a | 8.94 | 0.64 | n/a | n/a |
| 2001 | IV | n/a | n/a | n/a | n/a | 5.13 | 1.11 | n/a | n/a | n/a | n/a | n/a | n/a |
| | V | n/a | n/a | n/a | n/a | n/a | n/a | 5.06 | 0.26 | n/a | n/a | n/a | n/a |
| | VI | n/a | n/a | n/a | n/a | 4.15 | 0.34 | n/a | n/a | n/a | n/a | n/a | n/a |

**Continuation Appendix 1.4**

| Year | Month | Pribiloff | | St.Matthew | | Navarin | | Koryak | | Olyutor | | Petropavlovsk-Kommandor | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | M | m | M | m | M | m | M | m | M | m | M | m |
| 2001 | VII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| | VIII | n/a | n/a | n/a | n/a | 7.63 | 0.37 | 13.99 | 0.34 | 10.58 | 0.59 | n/a | n/a |
| 2002 | IV | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 5.02 | 0.18 | n/a | n/a |
| 2003 | X – XI | n/a | n/a | n/a | n/a | 8.75 | 0.31 | n/a | n/a | n/a | n/a | n/a | n/a |
| | XI | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 7.11 | 0.27 | 10.11 | 0.66 |
| 2004 | VII | 8.08 | 0.36 | 7.75 | 0.24 | 8.56 | 0.25 | n/a | n/a | n/a | n/a | n/a | n/a |
| 3+ | | | | | | | | | | | | | |
| 1998 | VI | n/a | n/a | n/a | n/a | 2.32 | 0.12 | n/a | n/a | 7.08 | 0.52 | n/a | n/a |
| 1999 | VI | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 5.63 | 0.57 | n/a | n/a |
| | XI – XII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 10.62 | 0.79 | n/a | n/a |
| | XII | n/a | n/a | n/a | n/a | 9.73 | 0.43 | 11.09 | 0.55 | n/a | n/a | n/a | n/a |
| 2000 | VI | n/a | n/a | n/a | n/a | 4.66 | 0.24 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2001 | V | n/a | n/a | n/a | n/a | n/a | n/a | 3.26 | 0.64 | n/a | n/a | n/a | n/a |
| | VI | n/a | n/a | n/a | n/a | 4.64 | 0.74 | n/a | n/a | n/a | n/a | n/a | n/a |
| | VII | n/a | n/a | n/a | n/a | n/a | n/a | 9.72 | 0.34 | n/a | n/a | n/a | n/a |
| | VIII | n/a | n/a | n/a | n/a | 9.09 | 0.19 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2003 | X – XI | n/a | n/a | n/a | n/a | 8.51 | 0.35 | n/a | n/a | n/a | n/a | n/a | n/a |
| | XI | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 6.38 | 0.2 | n/a | n/a |
| 2004 | VII | 6.97 | 0.67 | 6.98 | 0.67 | 9.66 | 0.27 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2+ | | | | | | | | | | | | | |
| 1999 | VI | n/a | n/a | n/a | n/a | 3.11 | 0.32 | n/a | n/a | n/a | n/a | n/a | n/a |
| | XII | n/a | n/a | n/a | n/a | 9.72 | 0.26 | 11.49 | 0.28 | n/a | n/a | n/a | n/a |
| 2000 | VI | n/a | n/a | n/a | n/a | 6.72 | 0.38 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2001 | V | n/a | n/a | n/a | n/a | n/a | n/a | 3.47 | 0.73 | n/a | n/a | n/a | n/a |
| | VI | n/a | n/a | n/a | n/a | 4.99 | 0.54 | n/a | n/a | n/a | n/a | n/a | n/a |

**Continuation Appendix 1.4**

| Year | Month | Pribiloff |  | St.Matthew |  | Navarin |  | Koryak |  | Olyutor |  | Petropavlovsk-Kommandor |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  | M | m | M | m | M | m | M | m | M | m | M | m |
| 2003 | X – XI | n/a | n/a | n/a | n/a | 8.11 | 0.52 | n/a | n/a | n/a | n/a | n/a | n/a |
|  | XI | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 6.67 | 0.21 | n/a | n/a |
| 2004 | VII | 4.82 | n/a | 6.6 | 0.82 | 9.99 | 0.6 | n/a | n/a | n/a | n/a | n/a | n/a |
| 1+ |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1999 | XII | n/a | n/a | n/a | n/a | 9.31 | 2.64 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2000 | VI | n/a | n/a | n/a | n/a | 5.72 | 0.51 | n/a | n/a | n/a | n/a | n/a | n/a |
|  | X – XI | n/a | n/a | n/a | n/a | 5.32 | 0.65 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2003 | XI | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 3.11 | 0.33 | n/a | n/a |
| 2004 | VII | n/a | n/a | 7.6 | 0.22 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| 0+ |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1999 | XII | n/a | n/a | n/a | n/a | 9.01 | 1.03 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2003 | X – XI | n/a | n/a | n/a | n/a | 3.44 | 0.34 | n/a | n/a | n/a | n/a | n/a | n/a |

**Appendix 1.5.** Hepatosomatic index of the Bering Sea male pollock, by area and age (notation as in 1.1.)

| Year | Month | Pribiloff | | St.Matthew | | Navarin | | Koryak | | Olyutor | | Petropavlovsk-Kommandor | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | M | m | M | m | M | m | M | m | M | m | M | m |
| >10 years | | | | | | | | | | | | | |
| 1999 | VI | n/a | n/a | n/a | n/a | 3.7 | 0.19 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2000 | VII | n/a | n/a | n/a | n/a | 6.52 | 0.42 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2001 | IV | n/a | n/a | n/a | n/a | 8.85 | 0.58 | n/a | n/a | n/a | n/a | n/a | n/a |
| | V | n/a | n/a | n/a | n/a | n/a | n/a | 4.89 | 1.46 | n/a | n/a | n/a | n/a |
| | VI | n/a | n/a | n/a | n/a | 5.76 | 0.38 | n/a | n/a | n/a | n/a | n/a | n/a |
| | VIII | n/a | n/a | n/a | n/a | 7.01 | 0.28 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2002 | IV | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 6.41 | 0.41 | n/a | n/a |
| 2003 | X–XI | n/a | n/a | n/a | n/a | 7.87 | 0.52 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2004 | II | n/a | n/a | n/a | n/a | 6.02 | 0.32 | n/a | n/a | n/a | n/a | n/a | n/a |
| 5–10 years | | | | | | | | | | | | | |
| 1998 | VI | n/a | n/a | n/a | n/a | 3.95 | 0.43 | n/a | n/a | 5.74 | 0.12 | n/a | n/a |
| | VII | n/a | n/a | n/a | n/a | 4.22 | 0.18 | n/a | n/a | 5.96 | 0.33 | n/a | n/a |
| | VIII | n/a | n/a | n/a | n/a | n/a | n/a | 5.31 | 0.47 | 8.08 | 0.1 | n/a | n/a |
| | IX | n/a | n/a | n/a | n/a | 8.52 | 0.36 | 8.77 | 0.41 | n/a | n/a | n/a | n/a |
| | X | n/a | n/a | n/a | n/a | n/a | n/a | 11.24 | 0.21 | 8.26 | 0.21 | n/a | n/a |
| | XI | n/a | n/a | n/a | n/a | 8.82 | 0.36 | n/a | n/a | n/a | n/a | n/a | n/a |
| | XI–XII | n/a | n/a | n/a | n/a | n/a | n/a | 7.87 | 0.58 | 8.07 | 0.2 | n/a | n/a |
| 1999 | VI | n/a | n/a | n/a | n/a | 3.62 | 0.16 | 5.69 | 0.35 | 5.13 | 0.27 | n/a | n/a |
| | VII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 8.78 | 0.3 | n/a | n/a |
| | XI–XII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 12.26 | 1.09 | n/a | n/a |
| | XII | n/a | n/a | n/a | n/a | 8.04 | 0.23 | 11.21 | 0.41 | n/a | n/a | n/a | n/a |
| 2000 | VII | n/a | n/a | n/a | n/a | 5.71 | 0.17 | 9.02 | 0.38 | 9.13 | 0.63 | n/a | n/a |
| | VIII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 8.6 | 0.24 | n/a | n/a |
| 2001 | IV | n/a | n/a | n/a | n/a | 6.27 | 0.63 | n/a | n/a | n/a | n/a | n/a | n/a |
| | V | n/a | n/a | n/a | n/a | n/a | n/a | 4.55 | 0.16 | n/a | n/a | n/a | n/a |

**Continuation Appendix 1.5**

| Year | Month | Pribiloff | | St.Matthew | | Navarin | | Koryak | | Olyutor | | Petropavlovsk-Kommandor | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | M | m | M | m | M | m | M | m | M | m | M | m |
| 2001 | VI | n/a | n/a | n/a | n/a | 4.4 | 0.14 | n/a | n/a | n/a | n/a | n/a | n/a |
| | VII | n/a | n/a | n/a | n/a | n/a | n/a | 8 | 0.25 | 6.36 | 0.32 | n/a | n/a |
| | VIII | n/a | n/a | n/a | n/a | 6.06 | 0.23 | 9.5 | 0.52 | 9.57 | 0.25 | n/a | n/a |
| 2002 | IV | n/a | n/a | n/a | n/a | n/a | n/a | 5.97 | 0.27 | 5.57 | 0.13 | n/a | n/a |
| 2003 | X – XI | n/a | n/a | n/a | n/a | 6.59 | 0.19 | n/a | n/a | n/a | n/a | n/a | n/a |
| | XI | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 7.16 | 0.22 | 8.94 | 0.19 |
| 2004 | II | n/a | n/a | n/a | n/a | 6.02 | 0.32 | n/a | n/a | n/a | n/a | n/a | n/a |
| | VII | 6.93 | 0.6 | 6.88 | 0.4 | 6.7 | 0.4 | n/a | n/a | n/a | n/a | n/a | n/a |
| 4+ | | | | | | | | | | | | | |
| 1998 | VI | n/a | n/a | n/a | n/a | 3.94 | 0.71 | n/a | n/a | 6.2 | 0.32 | n/a | n/a |
| | VII | n/a | n/a | n/a | n/a | 5.28 | 0.34 | n/a | n/a | n/a | n/a | n/a | n/a |
| | VIII | n/a | n/a | n/a | n/a | n/a | n/a | 8.22 | 0.25 | 9.47 | 0.29 | n/a | n/a |
| | IX | n/a | n/a | n/a | n/a | 7.6 | 0.68 | 10.06 | 0.56 | n/a | n/a | n/a | n/a |
| | X | n/a | n/a | n/a | n/a | n/a | n/a | 8.41 | 0.65 | n/a | n/a | n/a | n/a |
| | XI – XII | n/a | n/a | n/a | n/a | n/a | n/a | 8.82 | 0.77 | 8.6 | 0.23 | n/a | n/a |
| 1999 | VI | n/a | n/a | n/a | n/a | 3.96 | 0.47 | 6.98 | 0.53 | 6.5 | 0.46 | n/a | n/a |
| | XI – XII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 11.77 | 0.52 | n/a | n/a |
| | XII | n/a | n/a | n/a | n/a | 8.27 | 0.43 | 11.17 | 0.31 | n/a | n/a | n/a | n/a |
| 2000 | VII | n/a | n/a | n/a | n/a | 5.32 | 0.38 | n/a | n/a | 9.13 | 0.63 | n/a | n/a |
| 2001 | IV | n/a | n/a | n/a | n/a | 6.71 | 0.18 | n/a | n/a | n/a | n/a | n/a | n/a |
| | V | n/a | n/a | n/a | n/a | n/a | n/a | 4.1 | 0.24 | n/a | n/a | n/a | n/a |
| | VI | n/a | n/a | n/a | n/a | 3.08 | 0.28 | n/a | n/a | n/a | n/a | n/a | n/a |

**Continuation Appendix 1.5**

| Year | Month | Pribiloff |  | St.Matthew |  | Navarin |  | Koryak |  | Olyutor |  | Petropavlovsk-Kommandor |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  | M | m | M | m | M | m | M | m | M | m | M | m |
| 2001 | VII | n/a | n/a | n/a | n/a | n/a | n/a | 12.01 | 0.5 | 11.71 | 0.63 | n/a | n/a |
|  | VIII | n/a | n/a | n/a | n/a | 7.41 | 0.45 | 12.41 | 0.44 | 11.51 | 0.6 | n/a | n/a |
| 2002 | IV | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 5.12 | 0.24 | n/a | n/a |
| 2003 | X–XI | n/a | n/a | n/a | n/a | 7.36 | 0.27 | n/a | n/a | n/a | n/a | n/a | n/a |
|  | XI | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 7.06 | 0.2 | 9.43 | 0.29 |
| 2004 | VII | 7.77 | 0.23 | 7.53 | 0.28 | 8.64 | 0.23 | n/a | n/a | n/a | n/a | n/a | n/a |
| 3+ |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1999 | VI | n/a | n/a | n/a | n/a | 3.52 | 0.38 | n/a | n/a | 6.32 | 0.91 | n/a | n/a |
|  | XI–XII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 8.55 | 0.51 | n/a | n/a |
|  | XII | n/a | n/a | n/a | n/a | 8.55 | 0.51 | 12.09 | 0.38 | n/a | n/a | n/a | n/a |
| 2000 | VI | n/a | n/a | n/a | n/a | 4.9 | 0.29 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2001 | V | n/a | n/a | n/a | n/a | n/a | n/a | 3.57 | 0.55 | n/a | n/a | n/a | n/a |
|  | VI | n/a | n/a | n/a | n/a | 4.72 | 0.48 | n/a | n/a | n/a | n/a | n/a | n/a |
|  | VII | n/a | n/a | n/a | n/a | n/a | n/a | 10.18 | 0.43 | n/a | n/a | n/a | n/a |
|  | VIII | n/a | n/a | n/a | n/a | 8.64 | 1.11 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2003 | X–XI | n/a | n/a | n/a | n/a | 8.61 | 0.54 | n/a | n/a | n/a | n/a | n/a | n/a |
|  | XI | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 6.02 | 0.21 | n/a | n/a |
| 2004 | VII | 7.53 | 0.71 | 8 | 0.38 | 10.1 | 0.25 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2+ |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1999 | VI | n/a | n/a | n/a | n/a | 3.43 | 0.31 | n/a | n/a | n/a | n/a | n/a | n/a |
|  | XII | n/a | n/a | n/a | n/a | 9.44 | 0.22 | 11.75 | 0.25 | n/a | n/a | n/a | n/a |
| 2000 | VI | n/a | n/a | n/a | n/a | 4.57 | 0.56 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2001 | V | n/a | n/a | n/a | n/a | n/a | n/a | 3.97 | 0.53 | n/a | n/a | n/a | n/a |
|  | VI | n/a | n/a | n/a | n/a | 4.24 | 0.32 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2003 | X–XI | n/a | n/a | n/a | n/a | 7.91 | 0.4 | n/a | n/a | n/a | n/a | n/a | n/a |

**Continuation Appendix 1.5**

| Year | Month | Pribiloff | | St.Matthew | | Navarin | | Koryak | | Olyutor | | Petropavlovsk-Kommandor | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | M | m | M | m | M | m | M | m | M | m | M | m |
| 2003 | XI | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 6.11 | 0.2 | n/a | n/a |
| 2004 | VII | n/a | n/a | 7.75 | 0.85 | 9.82 | 0.68 | n/a | n/a | n/a | n/a | n/a | n/a |
| 1+ | | | | | | | | | | | | | |
| 1999 | XII | n/a | n/a | n/a | n/a | 10.35 | 2.08 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2000 | VI | n/a | n/a | n/a | n/a | 6.24 | 0.72 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2001 | VI | n/a | n/a | n/a | n/a | 4.78 | 0.11 | n/a | n/a | n/a | n/a | n/a | n/a |
| | X – XI | n/a | n/a | n/a | n/a | 5.55 | 0.41 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2003 | XI | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 3.15 | 0.19 | n/a | n/a |
| 2004 | VII | n/a | n/a | 7.5 | 0.54 | 9.82 | 0.68 | n/a | n/a | n/a | n/a | n/a | n/a |
| 0+ | | | | | | | | | | | | | |
| 1999 | XII | n/a | n/a | n/a | n/a | 9.01 | 1.03 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2003 | X – XI | n/a | n/a | n/a | n/a | 3.44 | 0.34 | n/a | n/a | n/a | n/a | n/a | n/a |

**Appendix 1.6.** Spleensomatic index of the Bering Sea female pollock, by area and age (notation as in 1.1.)

| Year | Month | Pribiloff | | St.Matthew | | Navarin | | Koryak | | Olyutor | | Petropavlovsk-Kommandor | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | M | m | M | m | M | m | M | m | M | m | M | m |
| | | | | | | >10 years | | | | | | | |
| 1999 | VI | n/a | n/a | n/a | n/a | 0.19 | 0.001 | 0.192 | 0.022 | 0.203 | 0.002 | n/a | n/a |
| | XII | n/a | n/a | n/a | n/a | 0.156 | 0.015 | 0.16 | 0.028 | n/a | n/a | n/a | n/a |
| 2000 | VII | n/a | n/a | n/a | n/a | 0.158 | 0.009 | 0.186 | 0.015 | 0.176 | 0.016 | n/a | n/a |
| 2001 | IV | n/a | n/a | n/a | n/a | 0.15 | 0.009 | n/a | n/a | n/a | n/a | n/a | n/a |
| | V | n/a | n/a | n/a | n/a | n/a | n/a | 0.182 | 0.019 | n/a | n/a | n/a | n/a |
| | VI | n/a | n/a | n/a | n/a | 0.186 | 0.006 | n/a | n/a | n/a | n/a | n/a | n/a |
| | VII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.265 | 0.022 | n/a | n/a |
| | VIII | n/a | n/a | n/a | n/a | 0.153 | 0.018 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2002 | IV | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.194 | 0.008 | n/a | n/a |
| 2003 | X–XI | n/a | n/a | n/a | n/a | 0.174 | 0.009 | n/a | n/a | n/a | n/a | n/a | n/a |
| | XI | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.151 | 0.028 | n/a | n/a |
| 2004 | II | n/a | n/a | n/a | n/a | 0.164 | 0.003 | n/a | n/a | n/a | n/a | n/a | n/a |
| | | | | | | 5–10 years | | | | | | | |
| 1999 | VI | n/a | n/a | n/a | n/a | 0.165 | 0.006 | 0.182 | 0.007 | 0.186 | 0.006 | n/a | n/a |
| | VII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.172 | 0.01 | n/a | n/a |
| | XI–XII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.195 | 0.028 | n/a | n/a |
| | XII | n/a | n/a | n/a | n/a | 0.16 | 0.005 | 0.17 | 0.013 | n/a | n/a | n/a | n/a |
| 2000 | VII | n/a | n/a | n/a | n/a | 0.171 | 0.006 | 0.149 | 0.011 | 0.169 | 0.007 | n/a | n/a |
| | VIII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.205 | 0.007 | n/a | n/a |
| 2001 | IV | n/a | n/a | n/a | n/a | 0.178 | 0.026 | n/a | n/a | n/a | n/a | n/a | n/a |
| | V | n/a | n/a | n/a | n/a | n/a | n/a | 0.152 | 0.003 | n/a | n/a | n/a | n/a |
| | VI | n/a | n/a | n/a | n/a | 0.157 | 0.003 | n/a | n/a | n/a | n/a | n/a | n/a |
| | VII | n/a | n/a | n/a | n/a | n/a | n/a | 0.143 | 0.007 | 0.142 | 0.008 | n/a | n/a |
| | VIII | n/a | n/a | n/a | n/a | 0.137 | 0.008 | 0.162 | 0.008 | 0.135 | 0.004 | n/a | n/a |
| 2002 | IV | n/a | n/a | n/a | n/a | n/a | n/a | 0.135 | 0.009 | 0.168 | 0.005 | n/a | n/a |
| 2003 | X–XI | n/a | n/a | n/a | n/a | 0.182 | 0.004 | n/a | n/a | n/a | n/a | n/a | n/a |
| | XI | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.204 | 0.009 | 0.206 | 0.008 |

**Continuation Appendix 1.6**

| Year | Month | Pribiloff | | St.Matthew | | Navarin | | Koryak | | Olyutor | | Petropavlovsk-Kommandor | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | M | m | M | m | M | m | M | m | M | m | M | m |
| 2004 | II | n/a | n/a | n/a | n/a | 0.163 | 0.013 | n/a | n/a | n/a | n/a | n/a | n/a |
| | VII | 0.186 | 0.013 | 0.192 | 0.01 | 0.19 | 0.011 | n/a | n/a | n/a | n/a | n/a | n/a |
| | | | | | | 4+ | | | | | | | |
| 1999 | VI | n/a | n/a | n/a | n/a | 0.189 | 0.029 | 0.148 | 0.011 | 0.181 | 0.002 | n/a | n/a |
| | XI – XII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.184 | 0.016 | n/a | n/a |
| | XII | n/a | n/a | n/a | n/a | 0.162 | 0.01 | 0.146 | 0.007 | n/a | n/a | n/a | n/a |
| 2000 | VII | n/a | n/a | n/a | n/a | 0.21 | 0.004 | n/a | n/a | 0.139 | 0.016 | n/a | n/a |
| 2001 | IV | n/a | n/a | n/a | n/a | 0.131 | 0.017 | n/a | n/a | n/a | n/a | n/a | n/a |
| | V | n/a | n/a | n/a | n/a | n/a | n/a | 0.125 | 0.006 | n/a | n/a | n/a | n/a |
| | VI | n/a | n/a | n/a | n/a | 0.155 | 0.015 | n/a | n/a | n/a | n/a | n/a | n/a |
| | VII | n/a | n/a | n/a | n/a | n/a | n/a | 0.124 | 0.005 | 0.15 | 0.008 | n/a | n/a |
| | VIII | n/a | n/a | n/a | n/a | 0.12 | 0.006 | 0.114 | 0.013 | 0.159 | 0.043 | n/a | n/a |
| 2002 | IV | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.126 | 0.007 | n/a | n/a |
| 2003 | X – XI | n/a | n/a | n/a | n/a | 0.173 | 0.006 | n/a | n/a | n/a | n/a | n/a | n/a |
| | XI | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.139 | 0.007 | 0.357 | 0.039 |
| 2004 | VII | 0.166 | 0.01 | 0.174 | 0.006 | 0.176 | 0.006 | n/a | n/a | n/a | n/a | n/a | n/a |
| | | | | | | 3+ | | | | | | | |
| 1999 | XI – XII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.15 | 0.009 | n/a | n/a |
| | XII | n/a | n/a | n/a | n/a | 0.21 | 0.011 | 0.15 | 0.009 | n/a | n/a | n/a | n/a |
| 2000 | VI | n/a | n/a | n/a | n/a | 0.194 | 0.018 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2001 | V | n/a | n/a | n/a | n/a | n/a | n/a | 0.131 | 0.021 | n/a | n/a | n/a | n/a |
| | VI | n/a | n/a | n/a | n/a | 0.206 | 0.026 | n/a | n/a | n/a | n/a | n/a | n/a |
| | VII | n/a | n/a | n/a | n/a | n/a | n/a | 0.123 | 0.006 | n/a | n/a | n/a | n/a |
| | VIII | n/a | n/a | n/a | n/a | 0.109 | 0.011 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2003 | X – XI | n/a | n/a | n/a | n/a | 0.156 | 0.009 | n/a | n/a | n/a | n/a | n/a | n/a |
| | XI | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.136 | 0.006 | n/a | n/a |
| 2004 | VII | 0.145 | 0.015 | 0.153 | 0.008 | 0.152 | 0.008 | n/a | n/a | n/a | n/a | n/a | n/a |

**Continuation Appendix 1.6**

| Year | Month | Pribiloff | | St.Matthew | | Navarin | | Koryak | | Olyutor | | Petropavlovsk-Kommandor | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | M | m | M | m | M | m | M | m | M | m | M | m |
| | | | | | | 2+ | | | | | | | |
| 1999 | XII | n/a | n/a | n/a | n/a | 0.169 | 0.006 | 0.148 | 0.001 | n/a | n/a | | |
| 2000 | VI | n/a | n/a | n/a | n/a | 0.378 | 0.062 | n/a | n/a | n/a | n/a | | |
| 2001 | V | n/a | n/a | n/a | n/a | n/a | n/a | 0.198 | 0.025 | n/a | n/a | | |
| | VI | n/a | n/a | n/a | n/a | 0.176 | 0.014 | n/a | n/a | n/a | n/a | | |
| 2003 | X–XI | n/a | n/a | n/a | n/a | 0.135 | 0.007 | n/a | n/a | n/a | n/a | | |
| | XI | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.146 | 0.006 | | |
| 2004 | VII | 0.12 | n/a | n/a | n/a | 0.121 | 0.01 | n/a | n/a | n/a | n/a | | |
| | | | | | | 1+ | | | | | | | |
| 1999 | XII | n/a | n/a | n/a | n/a | 0.157 | 0.021 | n/a | n/a | n/a | n/a | | |
| 2003 | X–XI | n/a | n/a | n/a | n/a | 0.15 | 0.019 | n/a | n/a | n/a | n/a | | |
| | XI | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.174 | 0.025 | | |

**Appendix 1.7.** Spleensomatic index of the Bering Sea male pollock, by area and age (notation as in 1.1.)

| Year | Month | Pribiloff | | St.Matthew | | Navarin | | Koryak | | Olyutor | | Petropavlovsk-Kommandor | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | M | m | M | m | M | m | M | m | M | m | M | m |
| | | | | | | >10 years | | | | | | | |
| 1999 | VI | n/a | n/a | n/a | n/a | 0.231 | 0.002 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2000 | VII | n/a | n/a | n/a | n/a | 0.225 | 0.038 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2001 | IV | n/a | n/a | n/a | n/a | 0.155 | 0.044 | n/a | n/a | n/a | n/a | n/a | n/a |
| | V | n/a | n/a | n/a | n/a | n/a | n/a | 0.142 | 0.017 | n/a | n/a | n/a | n/a |
| | VI | n/a | n/a | n/a | n/a | 0.24 | 0.022 | n/a | n/a | n/a | n/a | n/a | n/a |
| | VIII | n/a | n/a | n/a | n/a | 0.217 | 0.051 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2002 | IV | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.221 | 0.009 | n/a | n/a |
| 2003 | X – XI | n/a | n/a | n/a | n/a | 0.252 | 0.02 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2004 | II | n/a | n/a | n/a | n/a | 0.176 | 0.008 | n/a | n/a | n/a | n/a | n/a | n/a |
| | | | | | | 5 – 10 years | | | | | | | |
| 1999 | VI | n/a | n/a | n/a | n/a | 0.181 | 0.009 | 0.157 | 0.016 | 0.205 | 0.018 | n/a | n/a |
| | VII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.173 | 0.009 | n/a | n/a |
| | XI – XII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.237 | 0.064 | n/a | n/a |
| | XII | n/a | n/a | n/a | n/a | 0.168 | 0.008 | 0.173 | 0.009 | n/a | n/a | n/a | n/a |
| 2000 | VII | n/a | n/a | n/a | n/a | 0.189 | 0.011 | 0.149 | 0.011 | 0.164 | 0.009 | n/a | n/a |
| | VIII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.217 | 0.014 | n/a | n/a |
| 2001 | IV | n/a | n/a | n/a | n/a | 0.147 | 0.013 | n/a | n/a | n/a | n/a | n/a | n/a |
| | V | n/a | n/a | n/a | n/a | n/a | n/a | 0.157 | 0.005 | n/a | n/a | n/a | n/a |
| | VI | n/a | n/a | n/a | n/a | 0.177 | 0.006 | n/a | n/a | n/a | n/a | n/a | n/a |
| | VII | n/a | n/a | n/a | n/a | n/a | n/a | 0.137 | 0.006 | 0.201 | 0.025 | n/a | n/a |
| | VIII | n/a | n/a | n/a | n/a | 0.147 | 0.011 | 0.127 | 0.009 | 0.148 | 0.007 | n/a | n/a |
| 2002 | IV | n/a | n/a | n/a | n/a | n/a | n/a | 0.149 | 0.008 | 0.187 | 0.007 | n/a | n/a |
| 2003 | X – XI | n/a | n/a | n/a | n/a | 0.21 | 0.006 | n/a | n/a | n/a | n/a | n/a | n/a |
| | XI | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.18 | 0.006 | 0.27 | 0.012 |
| 2004 | VII | 0.188 | 0.013 | 0.205 | 0.012 | 0.193 | 0.01 | n/a | n/a | n/a | n/a | n/a | n/a |

**Continuation Appendix 1.7**

| Year | Month | Pribiloff | | St.Matthew | | Navarin | | Koryak | | Olyutor | | Petropavlovsk-Kommandor | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | M | m | M | m | M | m | M | m | M | m | M | m |
| 4+ | | | | | | | | | | | | | |
| 1999 | VI | n/a | n/a | n/a | n/a | 0.146 | 0.017 | 0.161 | 0.026 | 0.138 | 0.005 | n/a | n/a |
| | XI–XII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.184 | 0.016 | n/a | n/a |
| | XII | n/a | n/a | n/a | n/a | 0.211 | 0.035 | 0.161 | 0.015 | n/a | n/a | n/a | n/a |
| 2000 | VII | n/a | n/a | n/a | n/a | 0.175 | 0.016 | n/a | n/a | 0.219 | 0.014 | n/a | n/a |
| 2001 | IV | n/a | n/a | n/a | n/a | 0.153 | 0.021 | n/a | n/a | n/a | n/a | n/a | n/a |
| | V | n/a | n/a | n/a | n/a | n/a | n/a | 0.122 | 0.005 | n/a | n/a | n/a | n/a |
| | VI | n/a | n/a | n/a | n/a | 0.163 | 0.012 | n/a | n/a | n/a | n/a | n/a | n/a |
| | VII | n/a | n/a | n/a | n/a | n/a | n/a | 0.122 | 0.008 | 0.142 | 0.008 | n/a | n/a |
| | VIII | n/a | n/a | n/a | n/a | 0.132 | 0.019 | 0.106 | 0.004 | 0.125 | 0.023 | n/a | n/a |
| 2002 | IV | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.182 | 0.031 | n/a | n/a |
| 2003 | X–XI | n/a | n/a | n/a | n/a | 0.177 | 0.009 | n/a | n/a | n/a | n/a | n/a | n/a |
| | XI | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.181 | 0.015 | 0.324 | 0.024 |
| 2004 | VII | 0.172 | 0.007 | 0.173 | 0.006 | 0.185 | 0.011 | n/a | n/a | n/a | n/a | n/a | n/a |
| 3+ | | | | | | | | | | | | | |
| 1999 | XI–XII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.173 | 0.011 | n/a | n/a |
| | XII | n/a | n/a | n/a | n/a | 0.172 | 0.012 | 0.15 | 0.01 | n/a | n/a | n/a | n/a |
| 2000 | VI | n/a | n/a | n/a | n/a | 0.19 | 0.022 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2001 | V | n/a | n/a | n/a | n/a | n/a | n/a | 0.128 | 0.016 | n/a | n/a | n/a | n/a |
| | VI | n/a | n/a | n/a | n/a | 0.164 | 0.013 | n/a | n/a | n/a | n/a | n/a | n/a |
| | VII | n/a | n/a | n/a | n/a | n/a | n/a | 0.147 | 0.014 | n/a | n/a | n/a | n/a |
| | VIII | n/a | n/a | n/a | n/a | 0.099 | 0.013 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2003 | X–XI | n/a | n/a | n/a | n/a | 0.168 | 0.011 | n/a | n/a | n/a | n/a | n/a | n/a |
| | XI | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.146 | 0.007 | n/a | n/a |
| 2004 | VII | 0.156 | 0.009 | 0.157 | 0.007 | 0.157 | 0.007 | n/a | n/a | n/a | n/a | n/a | n/a |

**Continuation Appendix 1.7**

| Year | Month | Pribiloff | | St.Matthew | | Navarin | | Koryak | | Olyutor | | Petropavlovsk-Kommandor | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | M | m | M | m | M | m | M | m | M | m | M | m |
| 2+ | | | | | | | | | | | | | |
| 2000 | VI | n/a | n/a | n/a | n/a | 0.246 | 0.013 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2001 | V | n/a | n/a | n/a | n/a | n/a | n/a | 0.128 | 0.001 | n/a | n/a | n/a | n/a |
| | VI | n/a | n/a | n/a | n/a | 0.156 | 0.018 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2003 | X – XI | n/a | n/a | n/a | n/a | 0.138 | 0.009 | n/a | n/a | n/a | n/a | n/a | n/a |
| | XI | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.157 | 0.005 | n/a | n/a |
| 2004 | VII | 0.1 | n/a | 0.141 | 0.061 | 0.124 | 0.013 | n/a | n/a | n/a | n/a | n/a | n/a |
| 1+ | | | | | | | | | | | | | |
| 2003 | X – XI | n/a | n/a | n/a | n/a | 0.108 | 0.021 | n/a | n/a | n/a | n/a | n/a | n/a |
| | XI | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.228 | 0.033 | n/a | n/a |

**Appendix 1.8.** Cardiosomatic index of the Bering Sea female pollock, by area and age (notation as in 1.1.)

| Year | Month | Pribiloff | | St.Matthew | | Navarin | | Koryak | | Olyutor | | Petropavlovsk-Kommandor | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | M | m | M | m | M | m | M | m | M | m | M | m |
| >10 years | | | | | | | | | | | | | |
| 1999 | VI | n/a | n/a | n/a | n/a | 0.344 | 0.007 | 0.29 | 0.017 | 0.298 | 0.011 | n/a | n/a |
| | XII | n/a | n/a | n/a | n/a | 0.257 | 0.033 | 0.198 | 0.01 | n/a | n/a | n/a | n/a |
| 2000 | VII | n/a | n/a | n/a | n/a | 0.259 | 0.006 | 0.268 | 0.031 | 0.244 | 0.011 | n/a | n/a |
| 2001 | IV | n/a | n/a | n/a | n/a | 0.296 | 0.033 | n/a | n/a | n/a | n/a | n/a | n/a |
| | V | n/a | n/a | n/a | n/a | n/a | n/a | 0.244 | 0.003 | n/a | n/a | n/a | n/a |
| | VI | n/a | n/a | n/a | n/a | 0.279 | 0.005 | n/a | n/a | n/a | n/a | n/a | n/a |
| | VII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.271 | 0.017 | n/a | n/a |
| 2002 | IV | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.328 | 0.025 | n/a | n/a |
| 2003 | X – XI | n/a | n/a | n/a | n/a | 0.245 | 0.005 | n/a | n/a | n/a | n/a | n/a | n/a |
| | XI | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.172 | 0.022 | n/a | n/a |
| 5 – 10 years | | | | | | | | | | | | | |
| 1999 | VI | n/a | n/a | n/a | n/a | 0.316 | 0.006 | 0.294 | 0.006 | 0.314 | 0.005 | n/a | n/a |
| | VII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.245 | 0.009 | n/a | n/a |
| | XI – XII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.258 | 0.009 | n/a | n/a |
| | XII | n/a | n/a | n/a | n/a | 0.251 | 0.006 | 0.221 | 0.01 | n/a | n/a | n/a | n/a |
| 2000 | VII | n/a | n/a | n/a | n/a | 0.255 | 0.006 | 0.256 | 0.004 | 0.25 | 0.003 | n/a | n/a |
| | VIII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.26 | 0.004 | n/a | n/a |
| 2001 | IV | n/a | n/a | n/a | n/a | 0.238 | 0.007 | n/a | n/a | n/a | n/a | n/a | n/a |
| | V | n/a | n/a | n/a | n/a | n/a | n/a | 0.244 | 0.003 | n/a | n/a | n/a | n/a |
| | VI | n/a | n/a | n/a | n/a | 0.253 | 0.002 | n/a | n/a | n/a | n/a | n/a | n/a |
| | VII | n/a | n/a | n/a | n/a | n/a | n/a | 0.236 | 0.01 | 0.251 | 0.005 | n/a | n/a |
| 2002 | IV | n/a | n/a | n/a | n/a | n/a | n/a | 0.263 | 0.011 | 0.262 | 0.003 | n/a | n/a |
| 2003 | X – XI | n/a | n/a | n/a | n/a | 0.239 | 0.002 | n/a | n/a | n/a | n/a | n/a | n/a |
| | XI | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.203 | 0.007 | 0.201 | 0.007 |
| 2004 | VII | 0.252 | 0.005 | 0.244 | 0.004 | 0.244 | 0.006 | n/a | n/a | n/a | n/a | n/a | n/a |

**Continuation Appendix 1.8**

| Year | Month | Pribiloff | | St.Matthew | | Navarin | | Koryak | | Olyutor | | Petropavlovsk-Kommandor | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | M | m | M | m | M | m | M | m | M | m | M | m |
| | | | | | | 4+ | | | | | | | |
| 1999 | VI | n/a | n/a | n/a | n/a | 0.287 | 0.019 | 0.286 | 0.014 | 0.289 | 0.016 | n/a | n/a |
| | XI – XII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.238 | 0.01 | n/a | n/a |
| | XII | n/a | n/a | n/a | n/a | 0.242 | 0.011 | 0.231 | 0.006 | n/a | n/a | n/a | n/a |
| 2000 | VII | n/a | n/a | n/a | n/a | 0.295 | 0.015 | n/a | n/a | 0.219 | 0.014 | n/a | n/a |
| 2001 | IV | n/a | n/a | n/a | n/a | 0.253 | 0.029 | n/a | n/a | n/a | n/a | n/a | n/a |
| | V | n/a | n/a | n/a | n/a | n/a | n/a | 0.268 | 0.013 | n/a | n/a | n/a | n/a |
| | VI | n/a | n/a | n/a | n/a | 0.251 | 0.008 | n/a | n/a | n/a | n/a | n/a | n/a |
| | VII | n/a | n/a | n/a | n/a | n/a | n/a | 0.241 | 0.009 | 0.276 | 0.006 | n/a | n/a |
| 2002 | IV | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.256 | 0.004 | n/a | n/a |
| 2003 | X – XI | n/a | n/a | n/a | n/a | 0.23 | 0.006 | n/a | n/a | n/a | n/a | n/a | n/a |
| | XI | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.202 | 0.006 | 0.22 | 0.01 |
| 2004 | VII | 0.246 | 0.005 | 0.247 | 0.004 | 0.238 | 0.003 | n/a | n/a | n/a | n/a | n/a | n/a |
| | | | | | | 3+ | | | | | | | |
| 1999 | XI – XII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.247 | 0.009 | n/a | n/a |
| | XII | n/a | n/a | n/a | n/a | 0.281 | 0.002 | 0.256 | 0.008 | n/a | n/a | n/a | n/a |
| 2000 | VI | n/a | n/a | n/a | n/a | 0.297 | 0.011 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2001 | V | n/a | n/a | n/a | n/a | n/a | n/a | 0.298 | 0.026 | n/a | n/a | n/a | n/a |
| | VI | n/a | n/a | n/a | n/a | 0.284 | 0.019 | n/a | n/a | n/a | n/a | n/a | n/a |
| | VII | n/a | n/a | n/a | n/a | n/a | n/a | 0.259 | 0.008 | n/a | n/a | n/a | n/a |
| 2003 | X – XI | n/a | n/a | n/a | n/a | 0.249 | 0.01 | n/a | n/a | n/a | n/a | n/a | n/a |
| | XI | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.201 | 0.004 | n/a | n/a |
| 2004 | VII | 0.241 | 0.016 | 0.256 | 0.01 | 0.253 | 0.006 | n/a | n/a | n/a | n/a | n/a | n/a |
| | | | | | | 2+ | | | | | | | |
| 1999 | XII | n/a | n/a | n/a | n/a | 0.29 | 0.009 | 0.259 | 0.008 | n/a | n/a | n/a | n/a |
| 2000 | VI | n/a | n/a | n/a | n/a | 0.366 | 0.011 | n/a | n/a | n/a | n/a | n/a | n/a |

**Continuation Appendix 1.8**

| Year | Month | Pribiloff | | St.Matthew | | Navarin | | Koryak | | Olyutor | | Petropavlovsk-Kommandor | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | M | m | M | m | M | m | M | m | M | m | M | m |
| 2001 | V | n/a | n/a | n/a | n/a | n/a | n/a | 0.272 | 0.026 | n/a | n/a | n/a | n/a |
| | VI | n/a | n/a | n/a | n/a | 0.262 | 0.018 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2003 | X−XI | n/a | n/a | n/a | n/a | 0.236 | 0.007 | n/a | n/a | n/a | n/a | n/a | n/a |
| | XI | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.237 | 0.007 | n/a | n/a |
| 2004 | VII | 0.241 | n/a | n/a | n/a | 0.276 | 0.008 | n/a | n/a | n/a | n/a | n/a | n/a |
| 1+ | | | | | | | | | | | | | |
| 1999 | XII | n/a | n/a | n/a | n/a | 0.367 | 0.023 | n/a | n/a | n/a | n/a | n/a | n/a |
| | X−XI | n/a | n/a | n/a | n/a | 0.22 | 0.011 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2003 | XI | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.278 | 0.032 | n/a | n/a |

**Appendix 1.9.** Cardiosomatic index of the Bering Sea male pollock, by area and age (notation as in 1.1.)

| Year | Month | Pribiloff | | St.Matthew | | Navarin | | Koryak | | Olyutor | | Petropavlovsk-Kommandor | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | M | m | M | m | M | m | M | m | M | m | M | m |
| | | | | | | >10 years | | | | | | | |
| 1999 | VI | n/a | n/a | n/a | n/a | 0.244 | 0.008 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2000 | VII | n/a | n/a | n/a | n/a | 0.276 | 0.003 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2001 | IV | n/a | n/a | n/a | n/a | 0.239 | 0.048 | n/a | n/a | n/a | n/a | n/a | n/a |
| | V | n/a | n/a | n/a | n/a | n/a | n/a | 0.198 | 0.01 | n/a | n/a | n/a | n/a |
| | VI | n/a | n/a | n/a | n/a | 0.244 | 0.008 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2002 | IV | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.252 | 0.003 | n/a | n/a |
| 2003 | X–XI | n/a | n/a | n/a | n/a | 0.231 | 0.006 | n/a | n/a | n/a | n/a | n/a | n/a |
| | | | | | | 5–10 years | | | | | | | |
| 1999 | VI | n/a | n/a | n/a | n/a | 0.282 | 0.007 | 0.265 | 0.007 | 0.304 | 0.013 | n/a | n/a |
| | VII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.228 | 0.004 | n/a | n/a |
| | XI–XII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.213 | 0.006 | n/a | n/a |
| | XII | n/a | n/a | n/a | n/a | 0.263 | 0.011 | 0.227 | 0.006 | n/a | n/a | n/a | n/a |
| 2000 | VII | n/a | n/a | n/a | n/a | 0.25 | 0.004 | 0.259 | 0.007 | 0.235 | 0.005 | n/a | n/a |
| | VIII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.25 | 0.008 | n/a | n/a |
| 2001 | IV | n/a | n/a | n/a | n/a | 0.263 | 0.019 | n/a | n/a | n/a | n/a | n/a | n/a |
| | V | n/a | n/a | n/a | n/a | n/a | n/a | 0.24 | 0.004 | n/a | n/a | n/a | n/a |
| | VI | n/a | n/a | n/a | n/a | 0.253 | 0.002 | n/a | n/a | n/a | n/a | n/a | n/a |
| | VII | n/a | n/a | n/a | n/a | n/a | n/a | 0.23 | 0.005 | 0.251 | 0.005 | n/a | n/a |
| 2002 | IV | n/a | n/a | n/a | n/a | n/a | n/a | 0.235 | 0.005 | 0.25 | 0.004 | n/a | n/a |
| 2003 | X–XI | n/a | n/a | n/a | n/a | 0.231 | 0.006 | n/a | n/a | n/a | n/a | n/a | n/a |
| | XI | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.195 | 0.008 | 0.215 | 0.008 |
| 2004 | VII | 0.245 | 0.007 | 0.246 | 0.006 | 0.236 | 0.004 | n/a | n/a | n/a | n/a | n/a | n/a |
| | | | | | | 4+ | | | | | | | |
| 1999 | VI | n/a | n/a | n/a | n/a | 0.267 | 0.01 | 0.297 | 0.013 | 0.298 | 0.019 | n/a | n/a |
| | XI–XII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.238 | 0.01 | н\д | n/a |
| | XII | n/a | n/a | n/a | n/a | 0.294 | 0.026 | 0.248 | 0.009 | н\д | н\д | н\д | n/a |

**Continuation Appendix 1.9**

| Year | Month | Pribiloff | | St.Matthew | | Navarin | | Koryak | | Olyutor | | Petropavlovsk-Kommandor | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | M | m | M | m | M | m | M | m | M | m | M | m |
| 2000 | VII | n/a | n/a | n/a | n/a | 0.286 | 0.016 | n/a | n/a | 0.225 | 0.012 | н\д | n/a |
| 2001 | IV | n/a | n/a | n/a | n/a | 0.263 | 0.019 | n/a | n/a | n/a | n/a | n/a | n/a |
| | V | n/a | n/a | n/a | n/a | n/a | n/a | 0.254 | 0.007 | n/a | n/a | n/a | n/a |
| | VI | n/a | n/a | n/a | n/a | 0.232 | 0.005 | n/a | n/a | n/a | n/a | n/a | n/a |
| | VII | n/a | n/a | n/a | n/a | n/a | n/a | 0.244 | 0.009 | 0.272 | 0.006 | n/a | n/a |
| 2002 | IV | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.271 | 0.009 | n/a | n/a |
| 2003 | X–XI | n/a | n/a | n/a | n/a | 0.229 | 0.008 | n/a | n/a | n/a | n/a | n/a | n/a |
| | XI | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.188 | 0.008 | 0.253 | 0.013 |
| 2004 | VII | 0.246 | 0.005 | 0.241 | 0.004 | 0.248 | 0.005 | n/a | n/a | n/a | n/a | n/a | n/a |
| 3+ | | | | | | | | | | | | | |
| 1999 | XI–XII | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.247 | 0.009 | n/a | n/a |
| | XII | n/a | n/a | n/a | n/a | 0.244 | 0.011 | 0.249 | 0.006 | n/a | n/a | n/a | n/a |
| 2000 | VI | n/a | n/a | n/a | n/a | 0.295 | 0.011 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2001 | V | n/a | n/a | n/a | n/a | n/a | n/a | 0.306 | 0.039 | n/a | n/a | n/a | n/a |
| | VI | n/a | n/a | n/a | n/a | 0.279 | 0.014 | n/a | n/a | n/a | n/a | n/a | n/a |
| | VII | n/a | n/a | n/a | n/a | n/a | n/a | 0.262 | 0.013 | n/a | n/a | n/a | n/a |
| 2003 | X–XI | n/a | n/a | n/a | n/a | 0.237 | 0.01 | n/a | n/a | n/a | n/a | n/a | n/a |
| | XI | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.206 | 0.006 | n/a | n/a |
| 2004 | VII | 0.245 | 0.011 | 0.289 | 0.013 | 0.262 | 0.005 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2+ | | | | | | | | | | | | | |
| 1999 | XII | n/a | n/a | n/a | n/a | 0.287 | 0.009 | 0.282 | 0.01 | n/a | n/a | n/a | n/a |
| 2000 | VI | n/a | n/a | n/a | n/a | 0.387 | 0.009 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2001 | V | n/a | n/a | n/a | n/a | n/a | n/a | 0.261 | 0.001 | n/a | n/a | n/a | n/a |
| | VI | n/a | n/a | n/a | n/a | 0.22 | 0.019 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2003 | X–XI | n/a | n/a | n/a | n/a | 0.236 | 0.008 | n/a | n/a | n/a | n/a | n/a | n/a |

**Continuation Appendix 1.9**

| Year | Month | Pribiloff | | St.Matthew | | Navarin | | Koryak | | Olyutor | | Petropavlovsk-Kommandor | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | M | m | M | m | M | m | M | m | M | m | M | m |
| 2003 | XI | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.244 | 0.011 | n/a | n/a |
| 2004 | VII | 0.22 | n/a | 0.278 | 0.022 | 0.282 | 0.01 | n/a | n/a | n/a | n/a | n/a | n/a |
| 1+ | | | | | | | | | | | | | |
| 2003 | X – XI | n/a | n/a | n/a | n/a | 0.236 | 0.019 | n/a | n/a | n/a | n/a | n/a | n/a |
| | XI | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.324 | 0.053 | n/a | n/a |

# CONTENTS

**Kotenev** ***Boris Nikolaevich*****, Glubokov** ***Alexander Ivanovich***

# Walleye pollock Theragra chalcogramma from the Navarin region and adjacent waters of the Bering sea: ecology, biology and stock structure

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