euphausiids may significantly affect survival of planktonic eggs and larvae and hence recruitment of sardine and other species of fish.

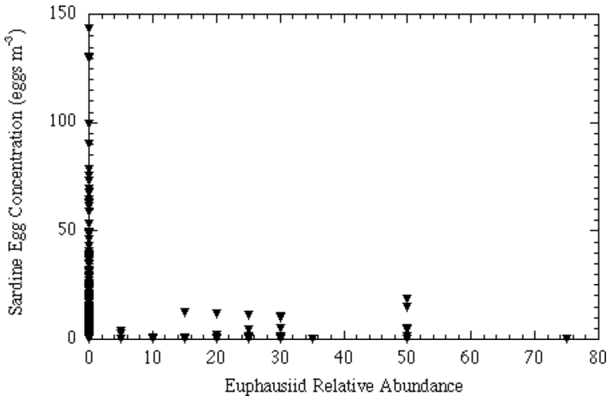


**Fig. 1** Concentration of eggs of Pacific sardine (*Sardinops sagax*) in relation to the relative abundance of euphausiids [0(absent), 100(maximal abundance)] in CUFES samples from CalCOFI cruise 9603JD (Checkley *et al.* in press).

Predation and competition require overlap in distributions of species populations, which, in turn, depend on available habitat. Climate variation will affect interactions between fish and euphausiids in part through expansion, contraction, and overlap of such habitats and hence the distributions of the species involved. A high priority should be given to characterizing such habitats and their variation. The use of standardized and coordinated techniques of data collection and analysis is recommended. This is one area in which PICES might take a leadership role. Additional work is also needed on the biology of euphausiids and, in particular, their feeding on fish eggs and larvae. Seminal work was done by Theilacker (1993), but further work is needed in order to quantify the predatory impact of euphausiids on fish eggs and larvae.

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## Shall we expect the Korf-Karaginsky herring migrations into the offshore western Bering Sea?


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In the 1990s, Pacific herring became one of the dominant species in the western Bering Sea pelagic fish community, especially in the sea shelf zone. The Korf-Karaginsky herring population has a leading role in total fishery biomass and herring fishery harvest in the western Bering Sea as in 1960s, when the harvest totalled up to 268,000 mt (Kachina, 1981). Whereas, during the 1980s, the harvest did not exceed 32,000 mt. Since the early 1990s, walleye pollock biomass has noticeably declined due to global climate change and reorganizations of the fish community structure. Herring have occupied a leading place in the southwestern Bering Sea pelagic layer likely since fall of 1994. Dr. N. I. Naumenko (pers. comm.) considers that the total Korf-Karaginsky herring biomass is equal to 1.7 million tonnes now. It is at least three times greater than for other pelagic fish species in the southwestern Bering Sea shelf.

Assessing the possible effects of increasing herring abundance on further reorganization of the community structure in the western Bering Sea is one from objectives of future studies. High abundance gives herring and important role as plankton consumers and as forage fish for upper trophic level predators. The dynamics of herring spatial distribution is of special interest in this aspect as it could determine role and contribution of herring to the organic matter transport through fish community trophic net in the Bering Sea shelf and offshore zones.

**Material and methods**

The TINRO-Center database of integrated ecosystem studies consists of materials from twelve complex expeditions carried out from 1986 to 1990 by Russian investigators in the western and central Bering Sea (Shuntov and Radchenko, 1999). Surveys in the central Berign Sea occurred only from 1988-1990. From 1991-1995, the survey area was limited to the southwestern part of the Bering Sea. The epipelagic layer (0-200 m) was investigated in all 12 expeditions. Fish sampling was conducted using a pelagic rope trawl, basically 108/528 m. The trawl bag (length 30-40 m) had mesh size of 30 mm and small-mesh insert (6-12 mm) of length 15m in back part. Archival data of 1,914 trawl hauls executed in these expeditions in upper epipelagic layer were analysed on distribution, abundance and feeding habits of fish and squids species to collate them with recently collected materials.

Since 1995 the bottom trawl and hydro-acoustic surveys were conducted in the western Bering Sea only. Walleye pollock stock assessment was the main objective of these expeditions until 1998. Last year, the first integrated expedition was conducted in this region. The set of expeditionary studies included oceanological, planktonic, bottom and trawl-acoustic surveys with accompanying work on data processing. For all common fish and squid species, feeding habits and biology characteristics have been examined. This regional coverage included the continental shelf and upper slope of the western Bering Sea between depths 49 to 509 m and totalled 37,000 square miles (Fig. 1). A bottom trawl survey (36 hauls) was conducted from August 21 to October 4, 1998. The distance between survey transects was 40 miles in the Anadry Gulf, Navarinsky region, and along the Koryak coast, but 20 miles in the Olyutorsky and Karaginsky Bays. The distance between hauls varied from 5 to 20 miles. The survey was executed by bottom trawl of 35/41m model. In October, an acoustic survey was conducted on the same area with several pelagic trawl hauls. These data give us additional data on herring distribution and seasonal migrations.

Herring stomachs and alimentary tracts were collected during biological investigations after trawl survey hauls. Daily diet calculation was conducted using the method of A. Kogan (1963) for fish that had well-expressed diurnal rhythms. Stomacbs from 205 herring specimens have been processed. Daily diet values and composition have been determined for all common pelagic and groundfish species.

**Result**

Data from 1998 showed that herring aggregations did not occur outside the shelf zone (Fig. 2) despite both direct and indirect evidence of increasing abundance. During the bottom trawl survey, herring accounted for only 1.5% of the total fish biomass. Indeed, it was determined by insignificant vertical opening of of the mouth of bottom trawl, was unable to catch whole schools of migrating herring.

Herring rarely occurred in trawl catches (no more than 5 fish per 30 minute haul) in the Anadry Gulf and northern waters off the Koryak Coast. Relatively high herring catches occurred in the western and central Koryak Coast (westward from 175°E**)** and in the eastern Olyutorsky Bay.

Maximal herring catch was at 1.5 tons, or about 5,000 fish per 30 minute haul (Fig. 2).

In October, herring was chiefly distributed in the Karaginsky and Olyutorsky bays (Fig. 3). Herring school records occurred in pelagic layer as pile-shaped spots, sometimes from bottom to sea surface. Maximal catch reached 6 mt, or more than 19,000 fish per 30 minutes pelagic haul. Herring aggregations had length of 2 miles and a height of about 25 m in that area.

Herring aggregations were represented by specimens sized 29 – 32 cm and at age 4+ to age 5+ in the Karaginsky and Olyutorsky Bays. This supports a previous understanding of the predominance of two year-classes in the Korf-Karaginsky herring population – 1993 and, to a lesser degree, 1994. These fish had body lengths (FL) 29-34 cm at survey time and contributed 75.5% of the total herring numbers on the Koryak shelf, and in the southwestern Bering Sea bays. However, the portion of older age groups was higher on the Koryak shelf (1991–1992 year-classes). Whereas, the numbers of herring aged 3+ (FL = 23-27 cm) was remarkable in the continental slope area off the Karaginsky and Olyutorsky bays. In near-shore waters, herring of third marine year (1996 year-class, FL = 21-23 cm) were fixed in survey catches. Age distribution of Korf-Karaginsky herring is presented in Figure 4 for the southwestern Bering Sea bays.

Several euphausiid species formed the base of the herring food supply in all survey regions (Table 1). Their contribution varied from 35.6 to 100% of the herring diet in different regions. Copepods contributed from 5 to 20.9% of the daily diet. Chaetognaths, gammarids, hyperiids, and decapods' larvae also occurred in the herring diet. Herring sized 30-35 cm had significant distinction from smaller size groups in the Karaginsky and Olyutorsky Bays. They mainly fed on walleye pollock juveniles which contributed 54.3% of daily diet. Stomach fullness varied from 42.7-151.7‰ for herring sized 25-40 cm. Smaller herring from the southwestern Bering Sea bays fed more intensively with average stomach fullness at 290.8‰. Daily diet value amounted 3.0% of body weight for fish sized 25-30 cm and 2.7% - for fish sized 30 – 35 cm.

**Discussion**

The annual cycle of the Korf-Karaginsky herring has been adequately studied. After spawning, it is well known that adult herring have an extensive migration route until late September-October. These migrations cover the continental shelf and slope zones from Goven Cape to the Navarin Cape (Panin, 1951; Prokhorov, 1967; Kachina, 1981).

Some relationship has been observed between the direction and intensity of herring migration with the oceanological regime in the area. In late June of 1991, adult herring occurred in the shallowest areas as seasonal heating did not significantly penetrate in the water column. Despite the anomalous high ocean temperature at the surface (7.5 – 9.6°C), it declined rapidly to 0.1 – 0.8°C at a depth of 20 – 25 m, especially in the eastern part of the Olyutorsky Bay. Water inflow from the offshore zone was observed in the central part of the bay. The main herring aggregations were distributed on the periphery of the gradient zone where water flowed onto the shelf (Fig. 5a).

The same situation occurred in July 1992. Weakly transformed Pacific waters have flowed there from the Near Strait region, and the resulting gradient zone formed in the western part of Olyutorsky Bay. Water flow onto the shelf was more intensive in 1992 than in 1991. Consequently, the herring concentration was significantly higher there. Adult herring (24-30 cm, mean 26.8 cm) catches reached 3 t per one-hour haul. Numerous herring schools occurred in the 4 – 25 m stratum (Fig. 5b).

**Table 1** Herring diet value and composition in the western Bering Sea, 21 August – 4 October 1998.

| | *Regions* | | | | | | |
|---|---|---|---|---|---|---|---|
| | Karaginsky and Olyutorsky Bays | | Off Koryak Coast | | | Anadyr Gulf | |
| **Herring size groups: →** | 20 - 25 | 25 - 30 | 30 - 35 | 35 - 40 | 25 - 30 | 30 - 35 | 25 - 30 |
| **Prey species** | | | | | | | |
| *Parasagitta elegans* | - | 2.1 | - | - | - | - | - |
| Guracoda | - | - | X | - | - | - | - |
| *Pseudocalanus minutus* | - | X | - | - | - | - | - |
| *Neocalanus cristatus* | 5.0 | 20.9 | 7.2 | 15.0 | 20 | 6.5 | - |
| *N. plumchrus* | - | - | 2.1 | 3.0 | - | - | - |
| *Eucalanus bungii* | - | - | - | - | - | 0.1 | - |
| *Candacia sp.* | - | - | 0.0 | - | - | - | - |
| *Meridia spacifica* | - | - | 0.3 | - | - | 2.4 | - |
| *Thysanoessa raschii* | 18.0 | 15.2 | 8.4 | - | - | 33.2 | 40 |
| *T. hinspinata* | - | - | - | - | - | 23.1 | - |
| *T. hinermis* | 15.0 | 20.4 | 27.2 | - | - | - | 60 |
| Euphausiacea (unid.) | 60.0 | 23.7 | - | 80.0 | 80 | - | - |
| *Parathemisto pacifica* | 2.0 | 10.2 | 0.5 | 2.0 | - | 34.7 | - |
| *Gammaridea* | - | - | - | - | X | - | - |
| Decapoda (larvae) | - | 4.9 | - | - | - | - | - |
| *Theragra chalcogramma* (aged 0+) | - | - | 54.3 | - | - | - | - |
| Fish weight (*g*) | 141 | 322 | 357 | 547 | 233 | 359 | 256 |
| Stomach numbers (n) | 14 | 70 | 55 | 9 | 9 | 28 | 20 |
| Number of empty stomachs | 0 | 19 | 6 | 0 | 6 | 10 | 4 |
| Food lump weight (*g*) | 4.1 | 1.4 | 2.1 | 8.3 | 1.4 | 2.0 | 0.7 |
| Mean Stomach fullness () | 290.8 | 42.7 | 60.1 | 151.7 | 60.1 | 55.4 | 28.1 |
| Depth (*m*) | 223.0 | 101-223 | 132-223 | 223.0 | 104.0 | 104-118 | 166.0 |

In early July of 1993, water inflow onto the shelf from the offshore zone was limited and did not effect the SST distribution. Slight curvatures of the isohaline contours indicated weak water inflow in the western Olyutorsky Bay (Fig. 5c). Herring were not aggregated in the bay at that time. Most herring schools likely migrated eastward from the Olyutorsky Cape. In trawl catches herring occurred in insignificant quantities (up to 0.23 tons per one-hour haul) in the depth range 60-120m.

In June–July of 1995 the situation occurred again like to 1992. Relatively weak flow was directed along the continental shelf edge from the Olyutorsky Cape to Karaginsky Island. Inflow of weakly transformed Pacific water was blocked by an anticyclonic eddy located 60 miles southwest of Olyutorsky Cape. Herring sized 26-37cm (mean 29.8 cm) occurred sporadically in trawl catches, mainly in the Olyutorsky Bay. The density of herring was in 3.5 times less than in 1993.

In 1991–1995, adult herring fed mainly upon euphausiids (*Thysanoessa inermis*) and copepods (*Eucalanus bungii*) in May – June, the period of the highest feeding intensity. During these two months, zooplankton consumption by herring contributes about 40% from annual food ration or approximately 1.95 kg of food per fish. In July, the herring daily diet is noticeable lower – from

11.7% of body weight during the feeding peak, to 2.9 – 3.0%, then to 1.9 – 2%. In August and September of 1991 – 1995, herring fed upon a wide spectrum of planktonic organisms in the Olyutorsky Bay: pteropod molluscs (25.2% on average, and in some years up to 77.9%), hyperiids (13.8%), pollock and capelin underyearlings (3.7–4%). During the 1980s, fish juveniles contributed 6% of herring diet. Herring annually consumed about 3,700 t of juvenile pollock and 6,400 t of capelin. On the area off Koryak Coast herring chiefly consumed copepods with *Neocalanus cristatus* predominant in August and September. The euphausiid portion has been estimated at 14% of daily diet in these months. In October the euphausiid portion increased and in December it reached 98% (Table 2).

In 1998, the herring diet composition was similar to that of the first half of 1990s. Euphausiids became a predominant food object and the smaller copepod *E. bungii* was replaced by *N. cristatus*. The daily diet value was higher for this season than in previous years of the study. According to our estimation, 1.7 million t of herring consumed about 45,000 t of food daily, mainly zooplankton (39,800 t). Euphausiids contributed about 21,500 t, equal to more than half of the total forage zooplankton biomass. The estimated euphausiid biomass, based on integrated surveys of the area, was 922,000 t on the continental shelf and slope zones off the Koryak Coast and in the southwestern Bering Sea bays. It means that herring are able to consume 64.1% of the total herring biomass during one month.

**Table 2** Kort-Karaginsky herring diet composition (%) by different size groups, by seasons in the western Bering Sea, 1986 – 1993.

| Food objects | Herring size groups | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0 + age | | 1 + -2 + age | | | | 3 +-10 + age | | | |
| | Fall | Winter | Spring | Summer | Fall | Winter | Spring | Summer* | Fall | Winter |
| Euphausids | 3.2 | 45.9 | 10.0 | 8.0 | 12.5 | 75.0 | 60.0 | 35.4 | 53.1 | 98.0 |
| Copepods | 32.9 | 29.4 | 70.0 | 64.4 | 37.5 | 10.5 | 38.0 | 20.8 | 5.0 | 1.2 |
| Hyperiids | 34.2 | 2.3 | 15.0 | 22.2 | 25.0 | - | 2.0 | 13.8 | 1.9 | + |
| Appendicularians | 29.7 | - | 5.0 | 0.8 | - | - | - | 25.2 | - | - |
| Pteropods | + | - | - | 4.2 | 17.5 | 2.0 | - | 0.7 | 25.2 | - |
| Chaetognats | - | 22.4 | - | + | + | - | - | 0.4 | 14.8 | 0.8 |
| Juvenile fish, eggs, larvae | - | - | + | 0.4 | 1.8 | 2.8 | + | 3.8 | - | - |
| Daily diet value (%BW) | 4.2 | 6.8 | 3.2 | 2.3 | | | 11.7** | 1.9 | 1.3 | 1.1 |

Remarks: * - for herring remaining in the Olyutorsky Bay.
** - during after-spawning period of high feeding intensity.

Data by season: Spring – April – May of 1989 and 1990; Summer – July of 1991 and 1992; Fall – September – Octocber of 1986 and 1987; Winter – late November of 1988, December of 1993.

It can be concluded that general pattern of water circulation likely has a greater effect on herring distribution than other features of physical environment. Herring aggregations are chiefly distributed in zones of water inflow onto the shelf from the offshore. Water flow onto the shelf provides a permanent transport of adult zooplankton organisms, which chiefly inhabit the offshore zone in summer season. Large zooplankton organisms predominate in the herring diet after spawning and their portion gradually increases until late fall. If water inflow has developed by June to early July, herring schools remain within the bay for feeding. Otherwise, the herring move quickly eastwards from Olyutorsky Cape. It should also be noted that herring aggregations have been observed along the Koryak Coast in the gradient zone periphery near the Central Bering Sea Current entrance of shelf and divergence (Prokhorov, 1967). In early August of 1987, herring catches reached there 18 tons per one-hour trawling.

Euphausiids are characterized by high potential production. The annual productivity to biomass ratio (P/B) is approximately 8 (Ponomareva, 1990). Since the main growth in weight of euphausiids takes place in warmer half-year, we can imagine that the euphausiid biomass is doubled every two months. These crustaceans are consumed rather intensively in the ecosystem. Walleye pollock, salmon, and other fishes feed on euphausiids. Some tightness is evident in the corresponding links of the shelf fish community trophic web.

Extpansion of feeding areas is an inherent characteristic of pelagic fishes during high abundance (Blaber, 1991). In the 1980s, abundant walleye pollock migrations were observed in the offshore Bering Sea basins and a large-scale fishery developed there. The total walleye pollock harvest in the Donut Hole reached 1.3 million tons in 1988. Will herring migrate in the offshore western Bering Sea to utilize its food resources or not?

The Korf-Karaginsky herring migrations through western Commander Basin were determined during the 1960s (Kachina, 1981). It is evident from herring distribution maps in this publication that herring were found offshore, although the author did not point out this feature of herring ecology. In 1992, the pollock fishing fleet observed herring migrating in the northern Aleutian Basin of the Bering Sea. Herring schools withdrew from shelf by up to 60 – 100 miles. Observers reported herring catches of 36 t per trawl haul in the offshore. This behaviour is also observed in the Atlantic–Scandianvian herring population, whose feeding area is chiefly situated above 1,000m depth. Therefore, feeding migration route seems possible for herring in the Bering Sea offshore water.

On the contrary, during the 1960s the Korf-Karaginsky herring biomass reached 3.5 million t, twice the present level (Naumenko et al., 1990). Based on the seasonal dynamics of herring daily diet value, annual Korf-Karaginsky population food ration totals at 24.3 million t (at level of herring biomass in 1.7 million tons). It is noticeably lower than larger plankton production in shelf areas, which can be estimated at 63.9 million tons (from annual biomass 6.2 million tons and P/B =10.3). Last year's euphausiid biomass increased in the herring feeding area and reached 309 $mg \cdot m^{-3}$. Besides, the main part of larger zooplankton consumed by herring is likely transported from the offshore sea with the water flow onto the shelf. Total annual euryphagous zooplankton production was estimated at 3.03 billion t for the whole Bering Sea, or 1,343 $t \cdot km^{-2}$ (Shuntov & Dulepova, 1995).

During the 1990s, significant growth of the Korf-Karaginsky herring biomass can be regarded as stable trend (Radchenko, 1998). However, further increase of the Korf-Karaginsky herring population can be prevented by spawning and early development conditions (Puschaeva, 1969). Several small inlets in the northern Karaginsky and Korf Bays can be regarded as favourable for local herring reproduction. Furthermore, natural mortality rates of egg and larvae sharply increase when spawning stocks are abundant (Puschaeva, 1968; Kachina, 1981). In last year, Dr. Naumenko (personal communication) has observed significant pre-spawning mortality of herring in the Anapka Inlet due to super-abundant herring spawner approach and inability to leave the inlet before reflux.

Thereby, a herring feeding strategy involves consumption of abundant and less motile organisms. During spring and summer feeding route herring aggregations are distributed in zones of permanent plankton transport and accumulation. In early summer, copepods predominate among planktonic crustaceans in

Olyutorsky Bay and it is reflected in herring diet composition. In May – June, in the shelf area off Koryak coast, the peak of herring feeding is related to euphausiids spawning, when euphausiids migrate into shallow areas and remain near the surface even during daytime (Ponomareva, 1990). "Grazing" as feeding strategy is not inherent for herring in the same degree as for pollock. This is indicated by the character of feeding migrations of these fish species: dense, quickly moving schools for herring and dispersion from dense spawning aggregations for pollock.

There are no "ecological limitations" (Blaber, 1991) for herring to migrate into deeper water and feed upon offshore resources. Nevertheless, herring ecology and feeding habits characterize this species as a typical shelf species. At the present level of herring biomass, there is a remote possibility of abundant herring migrations in the offshore Bering Sea. It means that the fish community in the deep-sea regions will have a predator deficit in its trophic structure.

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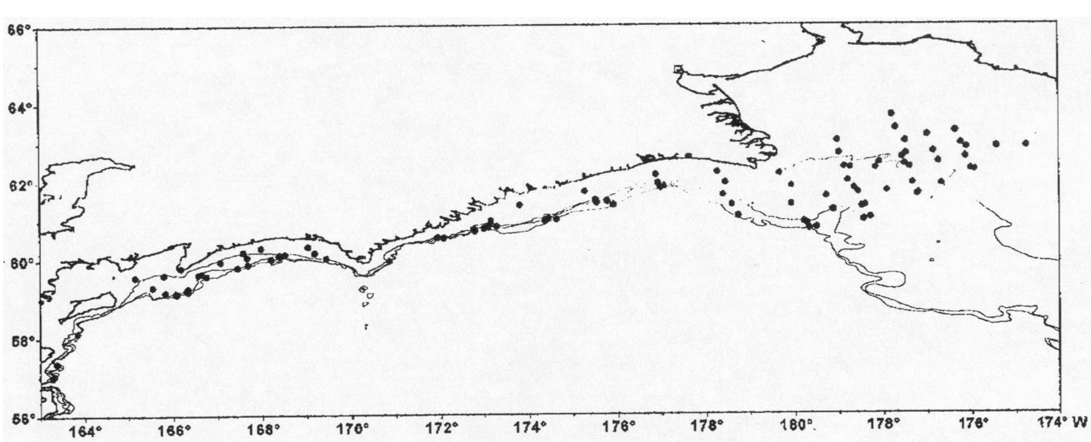


**Fig. 1** Scheme of the trawl survey.

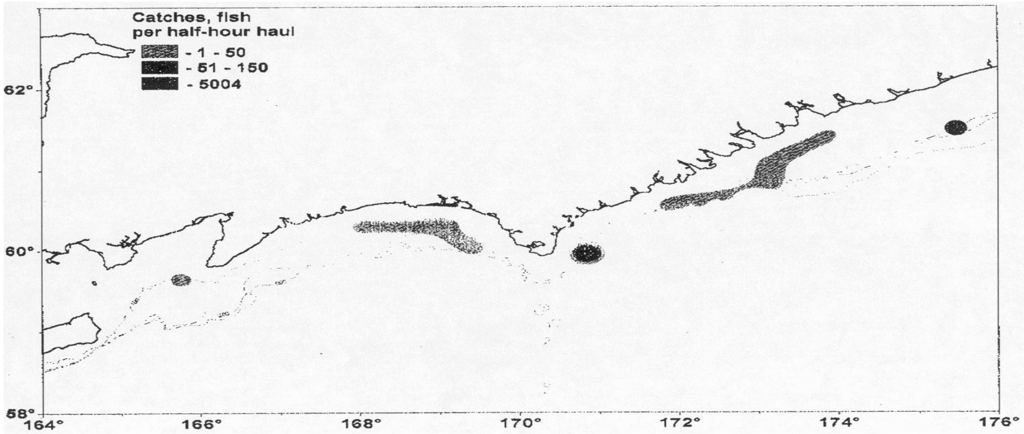


**Fig. 2** Pacific herring catch distribution according to *R/V "Professor Kaganovsky"* cruise data in the western Bering Sea, bottom trawl survey, August-September of 1998.

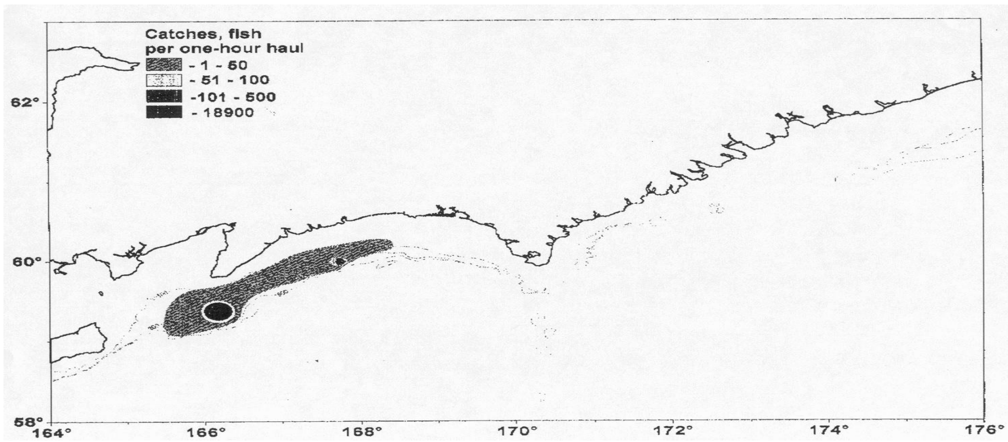


**Fig. 3** Pacific herring catch distribution according to *R/V "Professor Kaganovsky"* cruise data in the western Bering Sea, trawl-acoustic survey, October of 1998.

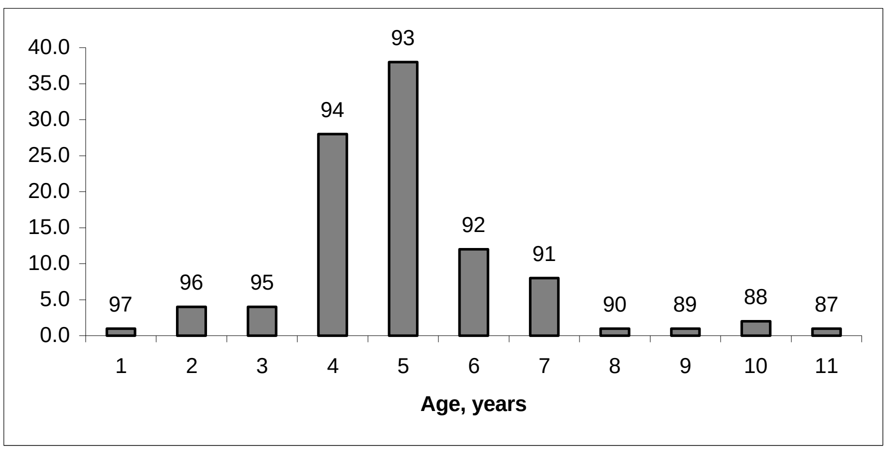


**Fig. 4** Herring age distribution in the Karaginsky and Olyutorsky Bays in the western Bering Sea, October 1998.

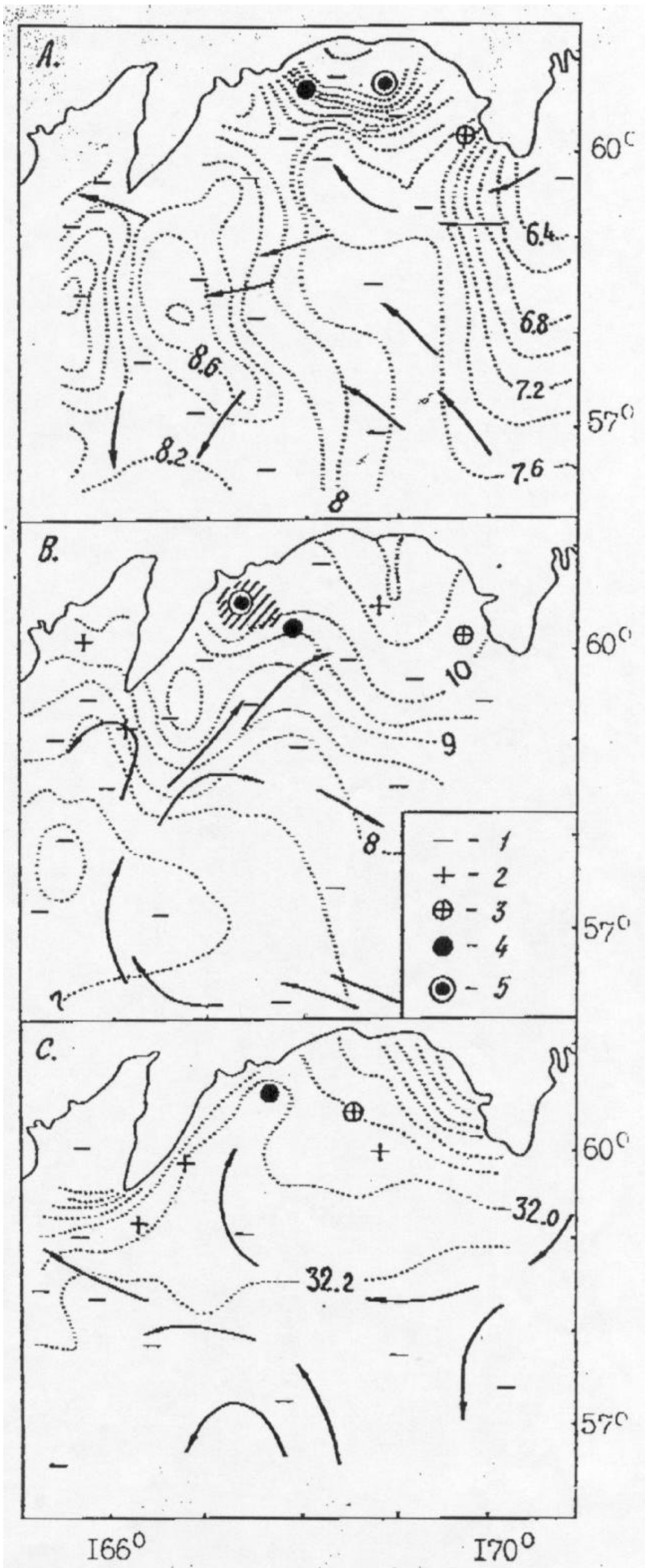


**Fig. 5** Herring Catch distribution in the Olyutorsky Bay in the western Bering Sea in Summer of 1991-1993. A) 6/22–7/5/1991; B) 7/3– 7/13/1992; C) 6/15–7/7/ 1993.

Legends:

1 – no catch;
2 – below 10;
3 – 10-100;
4 – 100-1000;
5 – above 1000 kg per one-hour haul.

Area with herring schools acoustic records is shadowed. SST (°C), Figure A, Figure B, and sea surface salinity (‰), Figure C, are presented.