# Influence of oceanological conditions of the West Kamchatka shelf waters on spawning grounds and on pollock egg distribution

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**Introduction**

From 1983 until the present the Pacific Research Institute of Fisheries and Oceanography (TINRO) has been carrying out a series of observations in areas of Pollock spawning grounds. These standard investigations spread over the basic shelf area of the Okhotsk Sea. We have analysed the data obtained from 21 expeditions near western Kamchatka (16 cruises were undertaken in April, and 5 cruises were held in March and in June). The data collected at more than 2000 stations have been processed. The water circulation has been analysed by dynamic topography method.

This study was done in order to pursue the following goals:

- to study the currents in western Kamchatka in early spring, as there is a lack of published information for this period,
- to determine the clusters of years with similar oceanological conditions,
- to analyse how much the spawning ground sites and pollock egg distributions differ from cluster to cluster of years, given similar oceanological conditions.

As the names given to the same currents by diferent authors vary, we accept the following terms: the West Kamchatka Current (WKC) for the northward warm flow along the Kamchatka slope and the Compensatory Current (CC) for the southward coastal counter-current, (in accordance with the names given by Davydov (1975) and Luchin (1982).

**Results and discussion**

In early spring the basic elements of water circulation, as seen on the dynamic topography charts, are the following: anticyclonic circulation of warm water of the WKC; cyclonic circulation of cold northern Okhotsk shelf waters – on the western periphery of the WKC, and the circulation of cold coastal waters, where the CC was observed in some years (Fig. 1).

Many features typical of the WKC are well known. From dynamic topography charts the WKC water looks like a system of anti-cyclonic eddies or like areas with anti-cyclonic curvature of streamlines. In the observed regions the surface current velocities were observed between 54°–57°N, in the area where the warm WKC water meets with cold water from the northern Okhotsk shelf. To the south of 53°N, the velocity of WKC is usually slow, as its streamline runs to the west from study area.

Moroshkin (1964), Luchin (1982) and Chernyavsky (1981) determined that the usual location of the WKC streamline to the north of the 500-m isobath varies between 152° and 154°E during the warm period. Our charts show that in April the WKC flows between 153°10′–154°20′E, that is, more to the east, than in warm seasons. This shift can be explained by seasonal variability of water density after long winter cooling, which reduces the zone of influence by the warm WKC water.

Very little data have been obtained about the CC. In 1910 Zhdanko published information about the drift of bottles southward along western Kamchatka. Kajiura (1949) and Leonov (1960) showed a southward current along western Kamchatka, too. From Moroshkin's (1964) charts and those of Davydov (1975) and Chernyavsky (1981), the CC was not shown and the WKC water moved in a northern direction between the coast and the slope. In 1982 Luchin confirmed the existence of the cold CC. He used Sarkyisyan's (1977) diagnostic model for current computation. Luchin assumed that the CC originated in shallow water to the south of Cape Utkolokskiy. In the summer, the CC is neither wide nor intensive, but these parameters increase from the summer to the autumn. Luchin (1987) explained the seasonal growth of the CC intensity both by a weakening of the WKC and by a strengthening of northeastward winds,

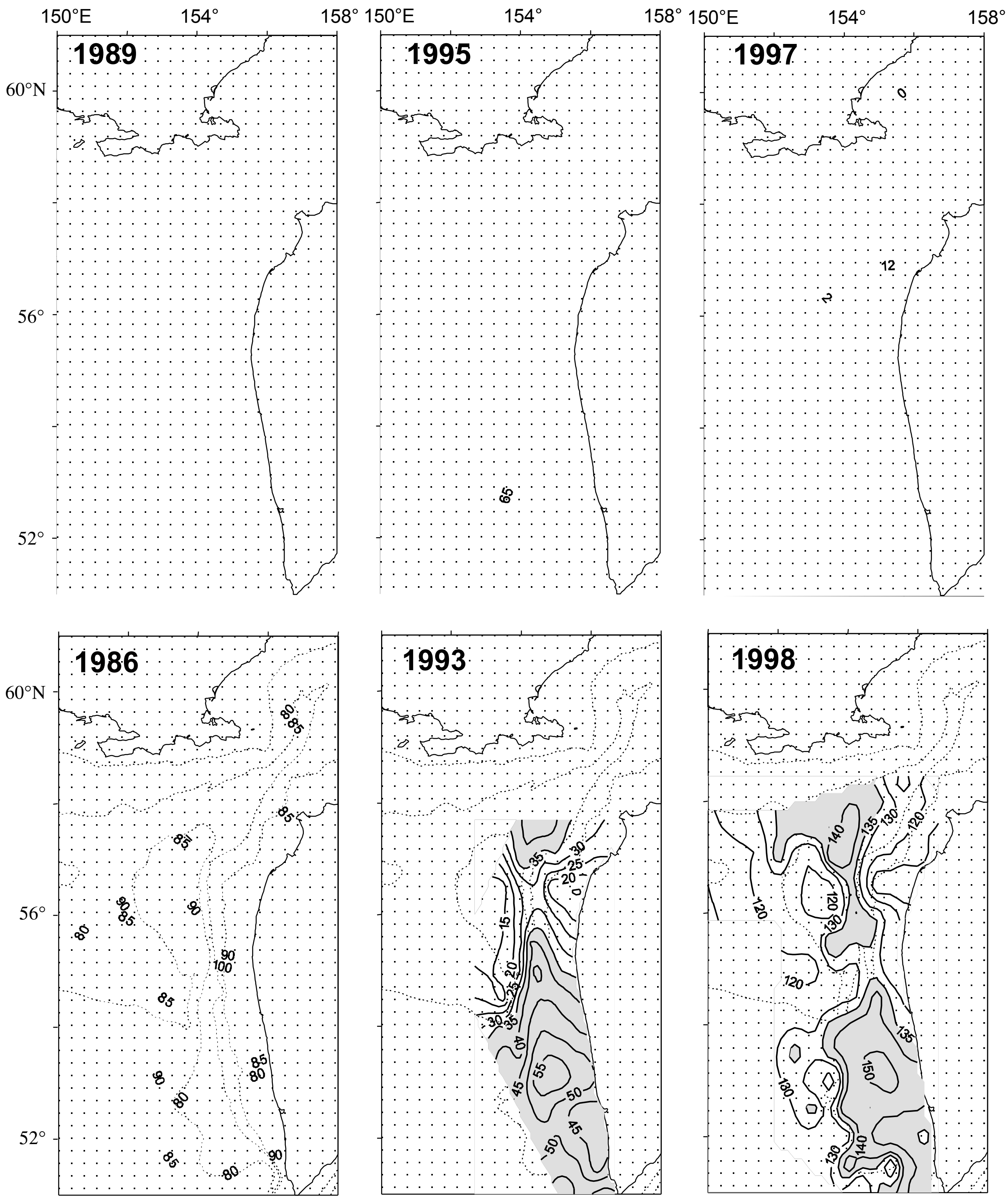


**Fig. 1** Typical water circulation in April showing (top) the years with an absence of the Compensatory Current (CC) and (bottom) the years with an intensive CC. Dashed is area of the West Kamchatka Current (WKC).

which cause an additional coastal southward flow from Shelikhov Bay.

Our charts of dynamic topography show that in April during 1983–1998 the CC was not formed in each year. The intensive CC, traced along a significant part of the western Kamchatka coast, was observed in 9 of 16 years: in 1985, 1986, 1988, 1991, 1993, 1996, 1998 and, probably, in 1987 and 1994 (the absence of data on salinity did not allow us to complete the current calculations for these years). In other years the CC was not observed or did not reach farther south than 56°–57°N (1984, 1989, 1990, 1992, 1995, 1997 and 1983, presumably, Fig. 1).

Studies were continued in order to analyze and compare particular oceanological conditions in a cluster of years with the intensive CC and in a cluster of years without the current.

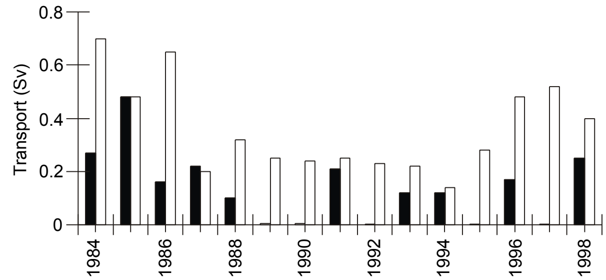


**Fig. 2** Water transport (Sv) in April for the layer for the layer 0–200 m (between West Kamchatka and 153°E). White bars denote transport of the WKC; black bars indicate transport of the CC. The years with intensive CC (transport ¤ 0.1 Sv) in April: 1985, 1986, 1988, 1991, 1993, 1996, 1998 and probably 1987 and 1994. The years with absence or weak CC (transport ○ 0.005 Sv) in April: 1984, 1989, 1990, 1992, 1995 and 1997.

According to our calculations, the southward water transport during the years of a weak CC was ○0.005 Sv. During the years with an intensive CC, the typical value of southward transport increased more than 10 times – about 0.1 Sv (Fig. 2). It is worth mentioning, that the values of transport and velocity obtained by the dynamic height calculation method are sufficient only for comparison, but do not work for calculation of exact values. Transport grew due to the increase of flow width, usually up to the 70–100 m isobath, to a maximum, up to the 150–170 m isobath.

Cyclonic circulation of coastal water is the main marker of the CC on dynamic topography charts. In the years when the CC was not found, the anticyclonic circulation of the WKC water was observed from the slope up to the coastline of western Kamchatka.

The cyclonic circulation of the CC means that the integrated density of its water is higher than the density of WKC waters. It is established that the lower temperature of the coastal water, as compared to the temperature of the WKC water, is not a sufficient condition for the formation of an intensive CC. Analysis has shown that coastal water salinity was usually higher or equal to the salinity of WKC waters in the years with an intensive CC (Fig. 3). In other years, when WKC water dominated along the coast, the salinity increased gradually with distance from the coast. The salinity of coastal waters in the years of an intensive CC is 0.3–0.6 psu higher than the salinity in the years when the CC was not found.

It is also known that in the Arctic seas salinity may increase due to ice formation or due to upwelling. The most intensive process of highly saline water formation took place in the upper part of the northwestern Okhotsk shelf and in the northern part of Shelikhov Bay (in areas with polynyas). Any increase of coastal water salinity due to local ice formation takes place in the winter along the Kamchatka coastline. Nevertheless, the local conditions solely can neither cause nor maintain high values of salinity that were observed here in the years with the intensive CC.

As noted on the dynamic topography charts, highly saline coastal water originated in the areas of Shelikov Bay. This water reaches the West Kamchatka coast either with the flow moving in a southern direction from Gizhiginskaya Guba along Pyagina Peninsula or along the Kamchatka coast. In both cases, the WKC cannot bring its waters to Shelikov Bay along the coast. It is interesting to note that the maximal value of high salinity of bottom waters in Gizhiginsky Bay was about 33.4–33.6 in the years with an absence of the CC and increased to 33.7–33.9 (up to 34.1) in the years with an intensive CC. The year-to-year variability of bottom water salinity in Gizhiginsky Bay correlates with the salinity in the shore zone of northern and central West Kamchatka with coefficient $R$ = 0.90–0.70.

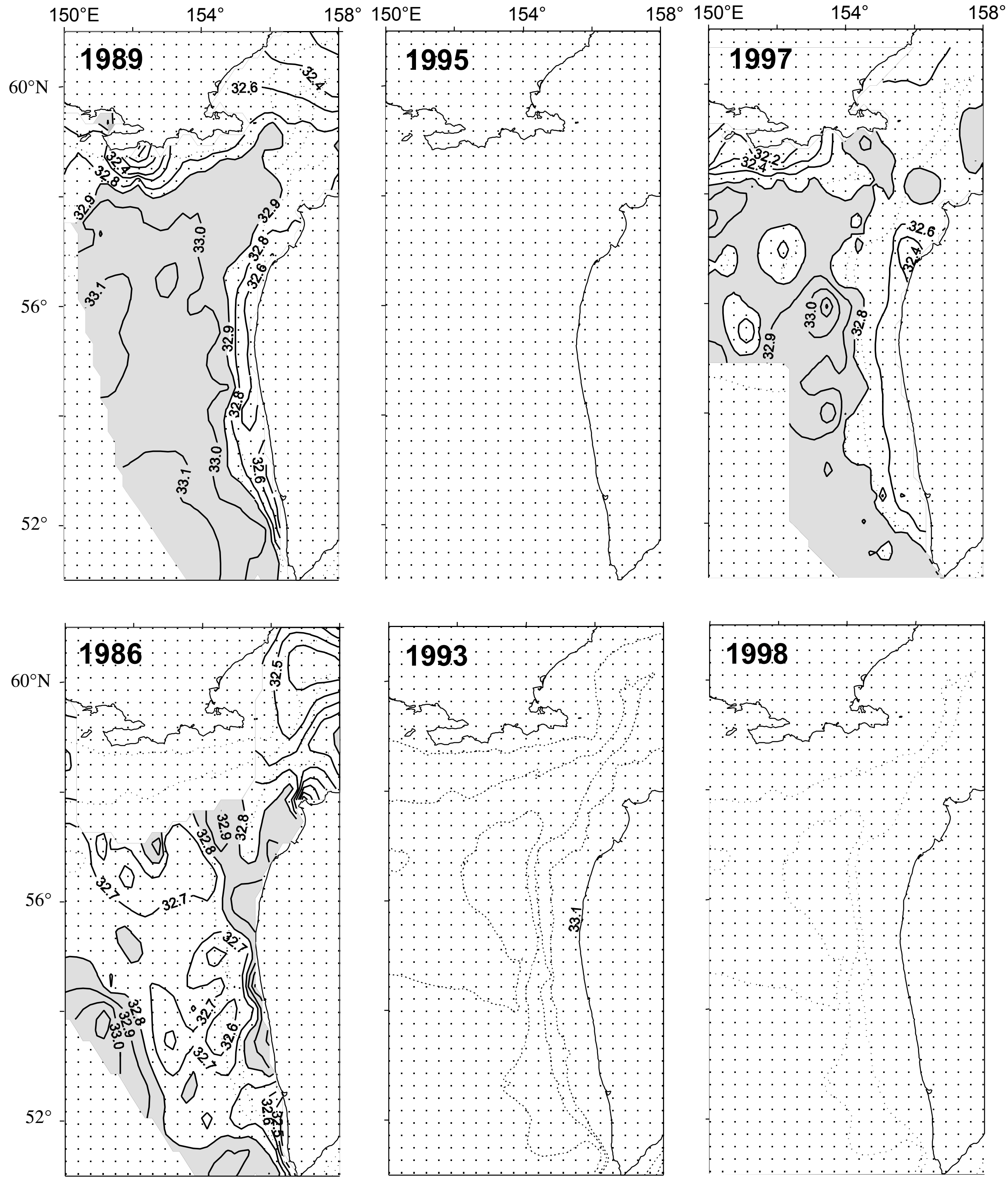


**Fig. 3** Typical distribution of surface salinity (psu) in April: (top) in the years with an absence of the CC and (bottom) in the years with an intensive CC. Shaded areas show higher salinity water.

The availability or absence of the CC significantly influences the water temperature in the convective layer from the surface to depths of 100–150 m. In April, the temperature of these depths and bottom temperature between the coast and the 100-120 m isobath is lower in the years with an intensive CC than in the years of its absence. For example, the temperature at 100 m was defined as “warm” or “normal” in the years with an absence of the CC and was defined as “cold” or “normal” in the years with an intensive CC. In other warm periods, the temperature anomaly was in the dichothermal layer with a probability of about 60–70%. If the Compensatory Current was stable and available in the summer months, the significant negative temperature anomalies and high positive salinity anomalies were observed in all water layers between the coast and 70–100 m isobath.

The combined charts of areas with cyclonic or anticyclonic water circulation were drawn for specified clusters of years. The analysis allowed us to conclude that the central location of cyclonic circulation in the northern Okhotsk shelf shifted to the south in the range of from 54°50O–56°30ON to 53°20O–56° 00ON – in cold years with an intensive CC (Fig. 4). The centres of anticyclonic circulation were between 155°E and the coast in the years with an absence of the CC. In this case, in the summer, the highest values of surface layer temperature and thickness as well as accumulation of river discharge were observed there. The areas with these parameters shifted to 30–50 miles from the coast in the years with an intensive CC, followed by the displacement of anti-cyclonic circulation

The vorticity of the current varied considerably from year to year. The number of the closed and semi-closed eddies from dynamic topography charts grew from 4–7 to 11–20, in case of an intensive CC. Davydov (1975) also noted that eddying increased during cold years in area west of the WKC. He explained this fact by a weakening of the WKC. We have not found the same direct correlation. Eddying and temperature variability depend on the intensity of both Currents, but the temperature range of the convective layer in spring and the temperature range of the dichothermal layer in summer depend rather more on the CC intensity than on the intensity of the WKC.

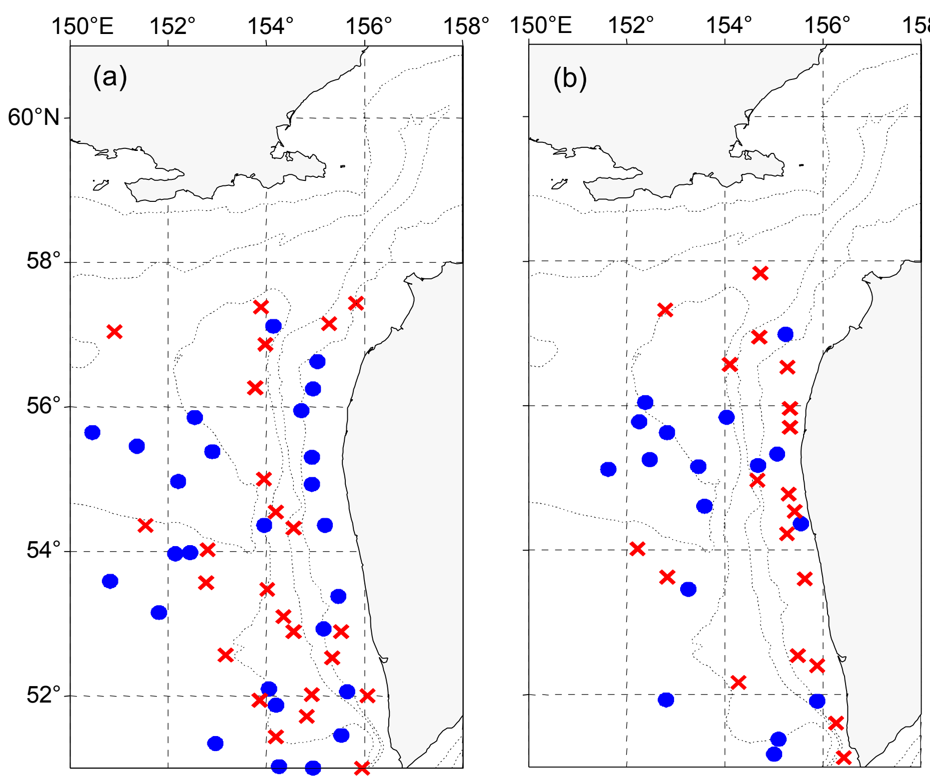


**Fig. 4** Combined locations of cyclones (solid circles) and anti-cyclones (crosses) in April in (a) years with an intensive CC and (b) years with the absence of the CC.

It is common knowledge that the variability of oceanological conditions influences the distribution and reproduction of living organisms. The conditions in a coastal zone play a special role because it is a place of spawning and an environment for eggs, larvae and younger generations of many species. We have found that the availability or absence of the coastal CC influences the oceanological conditions in this zone. Further, we have analysed spawning ground sites and pollock egg distributions in the years with intensive parameters and those with a weak CC. The distribution of pollock eggs of the first embryogeny stage was used as an indirect indicator of spawning ground locations. The distribution of eggs of the later stage was used to determine the direction of its drift. Some data on pollock egg distributions in all stages of growth in the years with an intensive or weak CC are presented in Figure 5. The following conclusions have been drawn:

1. In the years with an intensive CC, the main pollock spawning grounds were located to the south of 55°–54.5°N. In the years with an absence of the CC the main pollock spawning grounds were found north of 55°N.
2. In the years with an absence of the CC, spawning takes place at the 40–100 m isobath; in the years with an intensive CC spawning occurs at 60–150 m.
3. The more northern the spawning grounds lie, the deeper spawning takes place. It is well correlated with the location of a pre-bottom frontal zone formed by the lower edge of the convective layer.
4. Repeated observations show that pollock eggs are more often advected in the southern direction and farther off the coast in the years with an intensive CC. In the years with an absence of the CC, pollock eggs more often drift northward and towards the coast.
5. It is possible to assume that upwelling and divergence of water both accompany the cyclonic circulation of CC water, and may move some eggs not only from the coast, but also to the surf wave zone. Upwelling, together with the higher density of CC water, may keep pollock eggs in the surface layer longer than in years of CC absence.

In the years with an absence of the CC, productivity of young pollock generations had “normal” or “high” levels. In the years with an intensive CC, productivity of young pollock generations had “normal” or “low” levels.

In conclusion, some words about the probable reasons for CC formation are offered. The first and only hypothesis is hinted at by the name of the current – it partially compensates the transport of WKC water. However, an intensive CC was observed in the years with small, as well as large transport of WKC water to the northern part of the Okhotsk Sea. Probably the intensity of the CC depends rather on the inflow of WKC waters into Shelikov Bay. This needs further investigation.

It is interesting to note the regular concurrence of years with an intensive CC and the bottom salinity increase in Gizhiginsky Bay. Probably these phenomena are caused by specific atmospheric influences. For example, the increase of northern winds in winter over the Okhotsk Sea can cause sea level lowering and wind-induced upwelling along West Kamchatka, and polynya formation along the northern coast of the Sea. The latter serves as a favorable condition for the intensive formation of salty bottom water, including that in Gizhiginsky Bay. We plan to make this the subject of the further research.

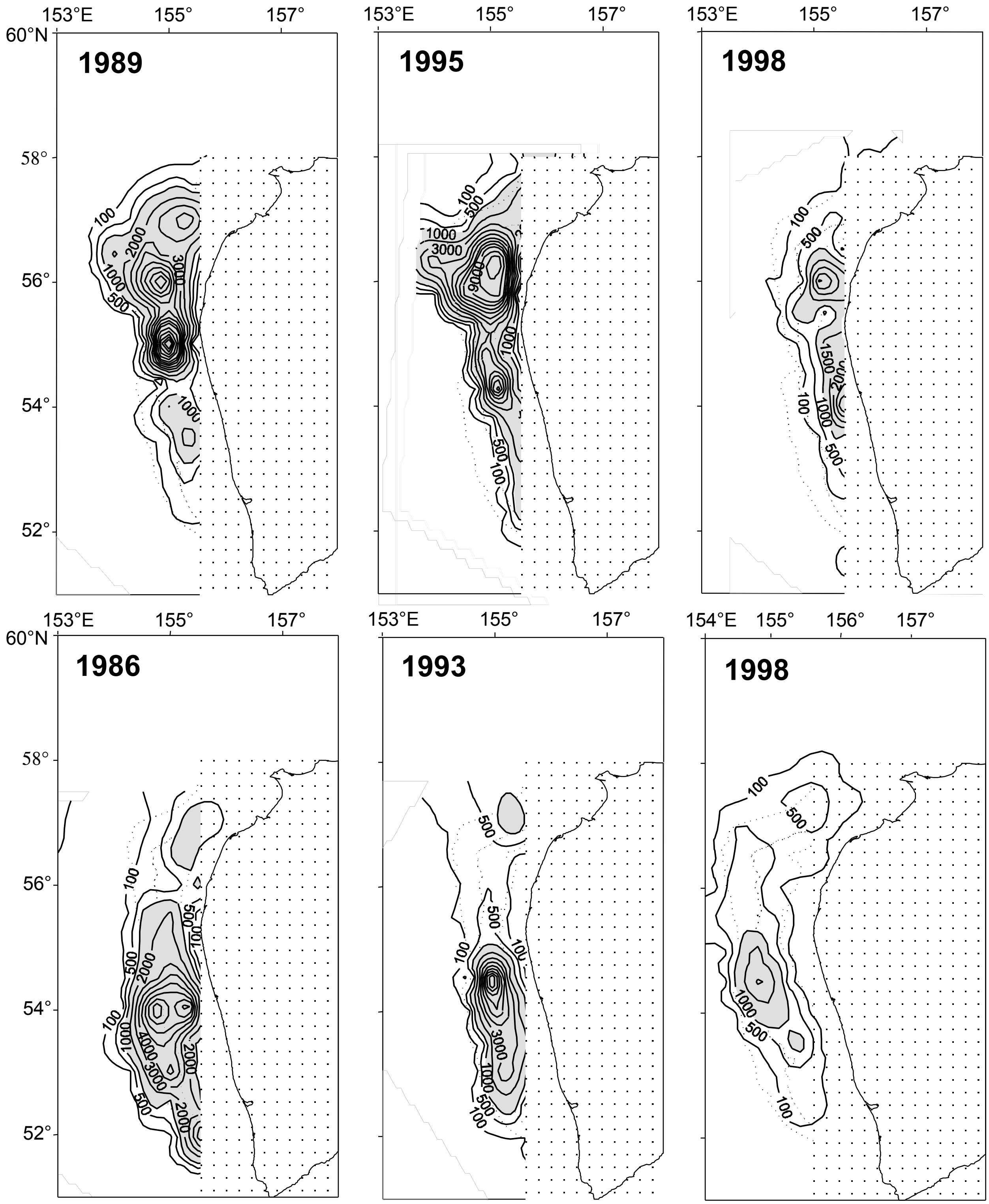


**Fig. 5** Typical distribution of pollock eggs in April in (top) the years with an absence of the CC and (bottom) the years with an intensive CC.

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