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by **A.D. Kovalev**

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SALINITY OF THE WATERS OF TAUISKAYA GULF AND THE ADJACENT
FISHING AREA DURING THE SUMMER PERIOD

By A.D. Kovalev

The area adjacent to Tauiskaya Gulf is one of the most important fishing areas of the Far East, where in individual years more than three million centners of foraging herring are caught, that is, about 30% of the herring catch of the Soviet Union.

The thermal regime of the northern part of the Okhotsk Sea and, in particular the fishing area adjacent to Tauiskaya Gulf has been investigated quite thoroughly. The salinity regime however has been studied to a far less extent. Meanwhile, data available at the present time from observations make it possible to throw some light not only on the salinity regime, but also on the variability of the salinity in the area of the feeding migration of the Okhotsk Sea herring.

The present work is devoted to an analysis of the long-term average salinity values computed for the middle of

* Numbers in the right-hand margin indicate the corresponding pages in the original.

each of five months of the year (June - October) on the basis of all the available hydrologic observations during the period from 1908 to 1969. In all, more than 1500 hydrologic observations were used in this study.

The computation of the means of several years' values of the salinity was carried out by a generally accepted method (Burkov, Tshipis, 1964) with a few changes which were described previously (Kovalev, 1972). The mean salinity values thus obtained made it possible to construct graphs of the vertical distribution, cross sections and maps, and also to trace the character of the variability of the salinity in the area of the feeding migration of the Okhotsk Sea herring.

Horizontal Distribution of Salinity

The main factors which control the salinity regime are the outflow of the rivers of Tauiskaya Gulf (Ola, Arman', Yana, Tauti and Motykleika) and the rate of flow of the Yamskoe Current.

The influence of the river outflow becomes evident first of all within the boundaries of Tauiskaya Gulf where the salinity as early as the end of April decreases from 33 to 32.5‰. The most significant salinity decrease occurs in the May-June period (Table 1).

In June two foci of salinity decrease develop in the Tauiskaya Gulf. In Ol'skii Bay there is a zone of intense salinity decrease (25-29‰) along the coast. From here the surface waters of the prevailing system of currents flow along the coast to the southeast and meet low-salinity waters (28-29‰) from Odyan Bay. Then, while moving on to Cape Skalistyi the surface waters mix to give a salinity of 29-30‰. From Cape Skalistyi the main mass of low-salinity waters flows on to Staritskii Peninsula and then into the western part of Tauiskaya Gulf. A small branch of these

waters swings off into Ol'skii Strait. It is interesting to note that between Zav'yalov Island and Staritskii Peninsula there is a zone of elevated salinity (up to 31.6‰) which is bounded by the 31‰ isohaline.

Таблица 1

Средняя многолетняя соленость, ‰

| 1 Пункты | 2 Месяцы | | | | | | |
|------------------|----------|--------|--------|----------|------------|-----------|----------|
| | Май 3 | Июнь 4 | Июль 5 | Август 6 | Сентябрь 7 | Октябрь 8 | Ноябрь 9 |
| 10 Бухта Нараева | 30,7 | 30,1 | 30,2 | 31,1 | 31,5 | 31,9 | 32,0 |
| 11 О. Спафарьева | 31,6 | 30,7 | 30,8 | 30,7 | 31,4 | 32,2 | 32,3 |

Table 1

Long-term average salinity, ‰

| | | |
|-------------|--------------|-----------------------|
| 1. Locality | 5. July | 9. November |
| 2. Month | 6. August | 10. Nagaeva Bight |
| 3. May | 7. September | 11. Spafar'eva Island |
| 4. June | 8. October | |

The most intense decrease in salinity is observed in the vicinity of the estuaries of the Tauri and Yana Rivers, and also in the area of Motykleiskii Bay where the salinity of the surface waters fluctuates within the range of 22.5 to 27.0‰. These low-salinity waters spread out in southerly and southeasterly directions and then between Zav'yalov and Spafar'ev Islands they flow out through Likhachev Strait into the open sea and are carried along by permanent currents to the southwest. Therefore in the western part of the area adjacent to Tauskaya Gulf the salinity of the surface waters does not exceed 32‰. The eastern part of the area is occupied by the Yamskoe waters (Chernyavskii, 1970), the salinity of which fluctuates within the range of 32.2 to 32.5‰. And it is only somewhat higher than 32.5‰ near the coast of Cape Alevina - Cape Bligan (Fig. 1).

However, it should be noted that the river outflow decreases the

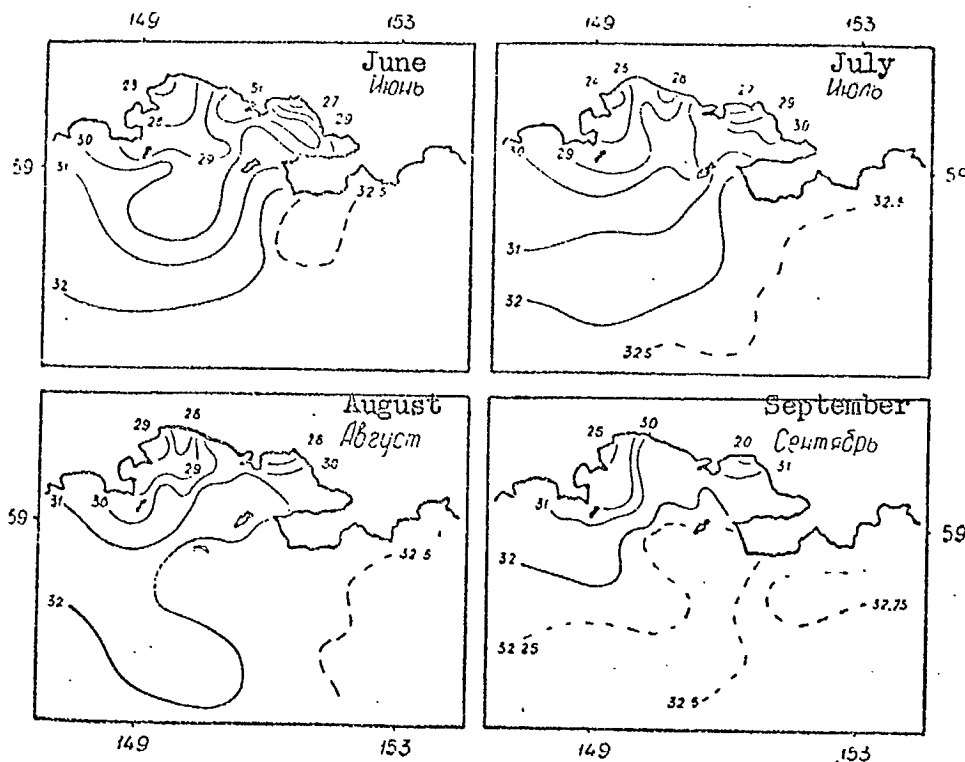


Рис. 1. Среднее многолетнее распределение солёности (‰) на поверхности моря в летний период.

Figure 1.

Distribution of salinity (‰) over the surface of the sea during the summer period (average of many years)

salinity of only the surface waters. Thus, in the western part of Taviskaya Gulf the depth of occurrence of the 32‰ isohaline fluctuates within the range of 7 to 10 m, and only in the area of Motykleiskii Bay does it sink to a depth of 10-15 m.

Between Zav'yalov Island and Staritskii Peninsula there is a zone where the depth of occurrence of the 32‰ isohaline does not exceed 4 m. As we noted previously (Kovalev, 1972), a stationary "patch" of cold waters has been observed in this same region. Thus, the upward movement of the 32‰ isohaline toward the surface of the sea and the presence of the "cold"

spot indicate that there is a zone of upwelling between Zav'yalov Island and Staritskii Peninsula.

In the eastern part of Tauiskaya Gulf the depth of occurrence of the 32‰ isohaline fluctuates within the range of 6-10 to 15-17 m. In Ol'skii Strait (between Zav'yalov Island and Koni Peninsula) the low-salinity layer decreases rapidly from 15 m at the latitude of Cape Taran to 7 m in the strait and at Cape Alevina the 32‰ isohaline emerges at the surface of the sea. Thus, the low-salinity waters in the eastern part of the area adjacent to Tauiskaya Gulf do not spread out, and the main factor which controls the salinity regime in this area is the rate of flow of the Yamskoe Current.

In contrast, the western part of the region adjacent to Tauiskaya Gulf is under the direct influence of the river outflow and here the depth of occurrence of the 32‰ isohaline has a very complex nature. In regions near the coast (on Shel'tinga Bay) the 32‰ isohaline sinks to a depth of 20-25 m, while to the west of Spafar'ev Island the low-salinity layer is thin (7-8 m). At 20-25 miles to the south of Spafar'ev Island an area is located where the low-salinity waters sink to 15-20 m. Afterwards the depth of occurrence of the 32‰ isohaline steadily decreases and it emerges at the surface of the sea (Fig. 2).

Spafar'ev Island, by dividing the flow of low-salinity water into two branches, favors the formation of an unusual zone where the layer of low-salinity water is thin, and thus is a barrier which prevents the mixing of surface and deep waters.

In July the pattern of the salinity distribution of the surface waters is similar to that of June. In Amakhtonzkii Bay it does not exceed 23-27‰.

and in Ol'skii Bay, 26-29‰. In the central part of Tauiskaya Gulf the salinity of the surface waters fluctuates within the range of 29.2 to 30.8‰ and it only reaches 31.2‰ at Staritskii Peninsula. In the area adjacent to Tauiskaya Gulf a general increase in salinity is noted in a southeasterly direction: at Spafar'ev Island it does not exceed 28-29‰ and in the east of the area the salinity of the surface waters increases to 32.0-32.8‰ (Fig.1).

The low-salinity layer increases almost everywhere. In the western part of Tauiskaya Gulf (in the Likhachev Strait) the 32‰ isohaline sinks to 20 m, in the eastern part to 20-24 m and only to the north of Zav'yalov Island does it rise up to within 7-10 m of the surface. In the western part of the area adjacent to Tauiskaya Gulf the low-salinity layer at the coast does not exceed 17-20 m, but at the latitude of 58° the 32‰ isohaline emerges at the surface of the sea (Fig. 2).

It should be noted that at a depth of 50 m the salinity changes only slightly; in Tauiskaya Gulf and in the western part of the adjacent area it does not exceed 32.5-32.9‰; in the eastern part of the adjacent area the salinity increases to 33.0-33.2‰.

At the bottom the influence of the river outflow shows up only in the Bays of Amakhtonskii and Ol'skii where the salinity fluctuates within the range of 31.3 to 32.0‰. The 32‰ isohaline passes along the coast at a distance of 5-15 miles from it and only comes within the boundaries of Tauiskaya Gulf between the Islands of Zav'yalov and Spafar'ev. In the area adjacent to Tauiskaya Gulf the salinity of the near-bottom waters does not exceed 33.0-33.6‰.

In August the salinity of the surface waters in Tauiskaya Gulf increases considerably owing to the decrease in the river outflow (summer

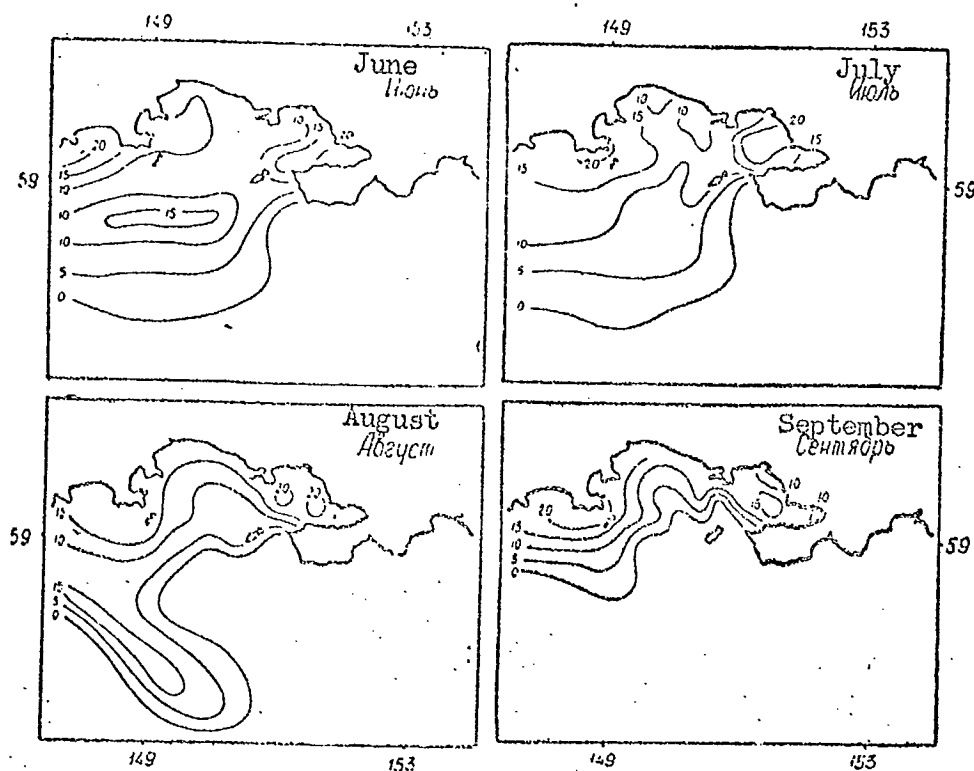


Рис. 2. Средняя многолетняя глубина залегания изогалыны 32‰ (мощность распресненного слоя) в летний период.

Figure 2

Depth of occurrence of the 32‰ isohaline (thickness of the low-salinity layer) during the summer period (average of many years)

low-water period). In areas in the vicinity of estuaries the salinity increases to 27-29‰ and over the greater part of Taviskaya Gulf it varies from 30 to 31‰. To the west of the area adjacent to Taviskaya Gulf the salinity of the surface waters does not exceed 32‰ and in the eastern part it fluctuates within the range of 32.4 to 32.8‰ (Fig. 1).

As the river outflow decreases the thickness of the low-salinity layer also decreases. In Taviskaya Gulf the depth of occurrence of the 32‰ isohaline does not exceed 15-22 m. In the western part of the area adjacent to Taviskaya Gulf the thickness of the low-salinity layer near the coast fluctuates within the range of 17 to 20 m and it decreases in a southerly

direction. However, in the southwestern part of the area adjacent to Tauiskaya Gulf the 32‰ isohaline sinks to a depth of 10-13 m (Fig. 2).

In September, owing to the increase in the river run-off (the autumn floods resulting from rain) the salinity of the surface waters falls but the area covered by the low-salinity waters is less than in August. In Amakhtonskii Bay the salinity of the surface waters decreases to 24-26‰, in Motykleiskii Bay to 26-28‰ and in Ol'skii Bay to 28-29‰. Over the remaining expanse of Tauiskaya Gulf the salinity fluctuates within the range of 31 to 32‰.

In the area adjacent to Tauiskaya Gulf the salinity of the surface waters varies only slightly -- from 32.00 to 32.95‰. Only in the northwestern part of the area (in Shel'tinga Bay) does it fall within the range of 30-32‰ (Fig. 1).

The greatest thickness of the low-salinity layer is observed in two regions: to the south of Shel'tinga Bay (20-25 m) and in the eastern part of Tauiskaya Gulf (14-18 m). In Amakhtonskii Bay the low-salinity waters extends to the bottom (Fig. 2).

However, even at a depth of 50 m the salinity varies only slightly. Over the expanse of Tauiskaya Bay it fluctuates within the range of 32.5 to 32.7‰. In the area adjacent to Tauiskaya Gulf the salinity varies from 32.4‰ in Shel'tinga Bay to 32.8-32.9‰ in the open sea. In the east of this area a "tongue" of Yamskoe waters with a salinity of 33.0-33.1‰ is observed. In the near-bottom layer the influence of the river outflow shows up only in the Bays of Amakhtonskii and Ol'skii where the salinity does not exceed 32‰.

60

In Tauiskaya Gulf the salinity of the near-bottom waters fluctuates

within the range of 32.0 to 32.7‰. The 32‰ isohaline passes through at the latitude of 58°40' - 58°50'.

In October the salinity of the surface waters in Tauiskaya Gulf and the adjacent area varies imperceptibly. Owing to a considerable decrease in the river run-off, low-salinity waters are encountered only in areas near estuaries. Over almost the whole of the expanse the salinity of the surface waters fluctuates within the range of 32-33‰.

Variability of the salinity

Variations in the salinity during the summer period are clearly indicated in the upper 10-20-meter layer (Fig. 2). Below this layer variations in the salinity are insignificant.

The large salinity decrease of the surface waters in the June-July period is caused by the increase in the river run-off resulting from intensive melting of the snow and in September by floods resulting from heavy rains. Of specific interest are the extreme values of the salinity, which make it possible not only to determine the routes and distribution boundaries of the low-salinity waters, but also to trace the possible routes of intrusion of sea waters into the expanse of Tauiskaya Gulf. Extreme values of the salinity were selected from all the available data, and maps of the distribution of the minimum and maximum salinity were constructed, and also maps of the range of its variability during the summer period. (June-September).

61

It can be seen from Fig. 3-A that the main sources of salinity decrease in the waters of the fishing area adjacent to Tauiskaya Gulf are the rivers of Amakhtonskii and Motykeiskii Bays, over the expanse of which the salinity of the surface waters during the flood period may fall to 4-6‰.

the rest of the expanse to 25-29‰, while the low-salinity waters do not spread south of Cape Alevina. Therefore in the eastern part of the area adjacent to Tauiskaya Gulf the influence of the river outflow is practically absent and here the salinity during the summer does not drop below 32‰.

The maximum salinity of the surface waters is found in a zone influenced by the Yamskoe Current and may reach 32.75-33.05‰. Over the remaining expanse of the area adjacent to Tauiskaya Gulf the maximum salinity does not exceed 32.25-32.75‰. Saline waters (more than 32‰) penetrate Tauiskaya Gulf in the area of Zav'yalov Island and may spread to Amakhtonskii and Ol'skii Bays. Only in the coastal parts of these bays does the maximum salinity of the surface waters not exceed 31.5-31.7‰, and in Motykleiskii Bay - 29-30‰.

As a result of large fluctuations in the rate of the river outflow into Tauiskaya Gulf and the adjacent area considerable variations in the salinity have been recorded during the summer period.

The maximum range of salinity fluctuations (22-27‰) is observed in Amakhtonskii Bay and a rather narrower range (15-22‰) in Motykleiskii Bay. Along the Ol'skii coast the range of salinity fluctuations does not exceed 6-10‰. It should be noted that the minimum variability of the salinity in Tauiskaya Gulf (1.3-2.0‰) is observed between Zav'yalov Island and Staritskii Peninsula.

In the western part of the area adjacent to Tauiskaya Gulf the range of salinity fluctuations in the coastal zone may reach 4-7‰ and in the open sea 2-3‰. The smallest fluctuations in salinity, the range of which does not exceed 0.5-1.0‰, are recorded in the east of the area, in a zone influenced by the Yamskoe Current (Fig. 3-B).

However, such a large variability of the salinity is observed only in the surface layer of the sea. Even at a depth of 10 m the range of the salinity fluctuations decreases considerably, especially in Tauiskaya Gulf. Thus, in Amakhtonskii and Motykleiskii Bays it does not exceed 4-5‰ and in Ol'skii Bay 2-3‰; that is, it is 4-5 times less than at the surface of the sea.

In the western part of the area adjacent to Tauiskaya Gulf the range of the salinity fluctuations decreases at a depth of 10 m from 2.8-3.7‰ near the coast to 1-2‰ at 58° latitude; in the east of the area it does not exceed 0.4-1.0‰ (Fig. 3-C).

Thus, the river outflow favors the formation of sharp vertical gradients of salinity. The largest values are noted in the Bays of Amakhtonskii, Motykleiskii and Ol'skii and may reach magnitudes of 3.3-3.0, 3-2 and 1.5-1.0 parts per thousand/meter respectively. In the area adjacent to Tauiskaya Gulf a gradual increase is noticed in the vertical salinity gradients from 0.015-0.025 in the southeast to 0.5-0.7 parts per thousand/meter in the area of Spafar'ev Island (Fig. 3-D). Such sharp vertical salinity gradients hinder the mixing of the waters in Tauiskaya Gulf and over a large part of the adjacent fishing area. Only in the eastern part of the area where the Yamskoe waters approach and where the vertical gradients of salinity and temperature are small, are conditions created which are favorable for the mixing and aeration of waters, which is confirmed by their high (up to 130-140% of saturation) content of oxygen.

Analysis of data from observations showed that the maximum salinity decrease in the surface waters occurs earliest of all in the coastal areas.

The marked horizontal gradients of the salinity in Tauiskaya Gulf which are due to the action of tidal currents cause large diurnal changes in salinity in the upper 10-20-meter layer. Observations at daily stations, carried out over the expanse of the Tauiskaya Gulf, show that the main factors which create diurnal changes in salinity are the tidal currents and the wind.

In Tauiskaya Gulf the tidal currents, like the tidal fluctuations in level, have an irregular semidiurnal nature with a large semidiurnal component. The amplitude of the tidal fluctuations in level under favorable astronomical conditions may reach 4 m. The maximum speeds of tidal currents do not exceed 0.8-1.0 knots. Non-periodical currents are small and depend upon both the rate of the river outflow and the system of winds prevailing over Tauiskaya Gulf.

Diurnal changes in salinity in Tauiskaya Gulf are quite significant and reach 5-10‰, while fluctuations in salinity during the summer period amount to 15-25‰ (Table 2).

Analysis of data from observations shows that the maximum salinity gradients are confined mainly to small bodies of water in a tidal inlet (Nagaeva Bight).

The minimum salinity at the surface of the sea is observed, as a rule, in the ebb tides which carry away the lower-salinity waters. An increase in salinity at the surface of the sea is observed which is due to the action of flood tides which transport the more saline waters toward the coast.

The wind exerts a twofold effect on the diurnal changes in salinity. With winds from the north a salinity decrease is observed over the expanse

of Tauiskaya Gulf while with winds from southern points of the compass the salinity of the surface waters increases.

Таблица 2

Экстремальные значения солености, ‰

| 1 Горизонт, м | 2 Восточная часть Тауйской губы | | 3 Западная часть Тауйской губы | |
|------------------|------------------------------------|-----------|-----------------------------------|-----------|
| | 4 максимум | 5 минимум | 4 максимум | 5 минимум |
| - 0 | 32,33 | 20,63 | 31,74 | 17,36 |
| 5 | 32,54 | 26,30 | 32,41 | 29,29 |
| 10 | 32,74 | 29,14 | 32,50 | 31,09 |
| 20 | 33,02 | 31,46 | 33,15 | 31,71 |

Table 2

Extreme values of the salinity, ‰

1. Level
2. Eastern part of Tauiskaya Gulf
3. Western part of Tauiskaya Gulf
4. maximum
5. minimum

Minimum salinity values over the expanse of Tauiskaya Gulf are observed during the simultaneous action of ebb-tide currents and north winds. In contrast, maximum salinity values in the surface layer are observed with south winds and currents flowing toward the coast.

However, none of the factors indicated above, taken individually, can explain the nature of the intradiurnal changes in salinity. The true explanation of these changes can only be obtained by taking into account the over-all hydrometeorological conditions, tidal currents and the distribution of salinity over the expanse of Tauiskaya Gulf.

Below the salinity discontinuity layer the diurnal variability of the salinity is determined, apparently, only by the tidal currents. Amplitudes of the fluctuations of the salinity isopleths

(internal waves) over the expanse of Tauiskaya Gulf may reach 6-12 m, and the period of their fluctuations 4-8 hours. Thus, salinity changes below the discontinuity layer are periodical in nature, which makes it possible to employ the methods of harmonic analysis for investigating the vertical fluctuations of the salinity isopleths.

An experiment in the use of the method of harmonic analysis by AANII (Arctic and Antarctic Scientific Research Institute) for investigating the internal waves in Tauiskaya Gulf (Kovalev, Chernyavskii, 1965) showed that the intradiurnal fluctuations of the salinity isopleths computed by this method agree quite well with full-scale data. It should also be noted that there is a definite relation between the amplitudes of the vertical fluctuations of the salinity isopleths and the phases of the moon, which confirms the tidal origin of the internal waves over the expanse of Tauiskaya Gulf.

In the fishing area adjacent to Tauiskaya Gulf the speed of the tidal currents increases from 1.0-1.2 knots in the west to 1.5-2.0 knots in the east of the area. The character of the tidal currents changes from irregular semidiurnal in the west to irregular diurnal in the east of the area.

In the west of the area adjacent to Tauiskaya Gulf where the arrival of low-salinity waters creates marked vertical salinity gradients, the fluctuations in salinity occur, as a rule, in opposite phases at the surface of the sea and in the near-bottom layers over a 24-hour period. The maximum tidal changes in salinity at the surface of the sea may reach 2-3‰, and in the near-bottom layers 0.5-1.0‰. When the semidiurnal component of the tidal currents is increasing, that is, near the times of the new moon

and the full moon, the intradiurnal changes in salinity have a semidiurnal period. During large declinations of the moon, when the diurnal components are increasing, the tidal fluctuations in salinity have a diurnal period.

To the east of the area adjacent to Tauiskaya Gulf, when the diurnal wave components of the tidal currents are increasing, the intradiurnal changes in salinity have, as a rule, a diurnal period in which the amplitude of the salinity fluctuations per day does not exceed 0.2-0.7‰ at the surface of the sea and 0.1-0.2‰ at the bottom.

It is interesting to note that the role of the diurnal components in the development of tidal salinity fluctuations usually increases in the near-bottom layers in comparison with the surface layer of the sea. This is explained by the fact that the proportion of the diurnal wave components in the tidal currents increases in the near-bottom layers of the area adjacent to Tauiskaya Gulf.

The maximum amplitudes of the tidal variability of the salinity and of its distribution over the expanse of Tauiskaya Gulf and the adjacent fishing area are of great practical importance. We constructed a map of the maximum tidal variability of the salinity based upon the data of multiserial stations (Fig. 5).

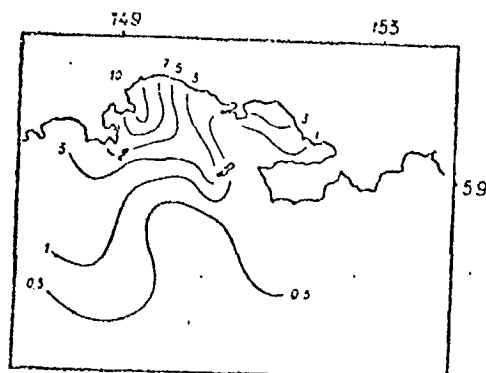


Рис. 5. Максимальная приливная изменчивость солености (‰) на поверхности моря.

Figure 5
Maximum tidal variability of the salinity (‰) at the surface of the sea.

Tidal fluctuations in salinity reach their highest values in Amakhtonskii Bay (7-10‰), Motykleiskii Bay (5-7‰) and Ol'skii Bay (3-4‰), and amount to 25-40% of the seasonal variability of the salinity in these areas. They are large also in the area to the southwest of Spafar'ev Island and in Sheltinga Bay (2-4‰). Over the remaining expanse of the area adjacent to Tauiskaya Gulf the tidal fluctuations in salinity are small (0.2-0.7‰). However, in virtue of the fact that the seasonal variability of the salinity is small here also, the amplitude of its tidal fluctuations amounts to 25-30% of its seasonal variability in the west and 50-70% in the east.

Thus, changes in salinity over a 24-hour period, which result from the action of tidal currents, amount to 25-70% of its seasonal variability, and may influence to a considerable extent the condition of water masses in the Tauiskaya Gulf and the adjacent fishing area.

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SALINITY OF THE TAUYSKAYA INLET WATERS AND ITS ADJACENT
FISHERING AREA IN SUMMER PERIOD

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Summary

The work is dedicated to the analysis of the many years average quantities of salinity waters calculated for the warm period of the year (june — october) on the grounds of the observations carried out in the period from 1908 to 1969. The reasons of space and vertical changeability of salinity from month to month were established and the short periods of salinity fluctuations of a tidal character were considered.

* This summary appears as it is in the original text.