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© *A. A. Konik*[1]*, *A. V. Zimin*[1,2], *O. A. Atadzhanova*[1,3], *E. I. Svergun*[1], *D. A. Romanenkov*[1], *E. V. Sofina*[1,4], *A. I. Varkentin*[1,5], *O. B. Tepnin*[1,5], *D. Ja. Saushkina*[1,5], 2024
© Translation from Russian: *E. S. Kochetkova*, 2024
[1]Shirshov Institute of Oceanology, Russian Academy of Sciences, 36 Nakhimovsky Prosp., Moscow, 117997, Russia
[2]St. Petersburg State University, 7–9 Universitetskaja Emb., St. Petersburg, 199034, Russia
[3]Marine Hydrophysical Institute, 2 Kapitanskaja Str., Sevastopol, 299011, Russia
[4]Russian State Hydrometeorological University, 79 Voronezhskaja Str., St. Petersburg, 192007, Russia
[5]Kamchatka branch of "Federal Research Institute of Fisheries and Oceanography" ("KamchatNIRO"), 18 Naberezhnaja Str., Petropavlovsk-Kamchatsky, 683000, Russia
*konikrshu@gmail.com

INTRA-DAY VARIABILITY OF VERTICAL WATER STRUCTURE AND DISTRIBUTIONS WALLEYE POLLOCK EGGS IN THE DEEP-SEA CANYONS OF AVACHA BAY: A FIELD EXPERIMENT DURING THE SPAWNING PERIOD

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Abstract

Tidal dynamics along the shelf break and continental slope of the Kamchatka Peninsula, adjacent to the Pacific Ocean, are a significant but underexplored factor influencing the hydrological variability. This variability affects the distribution of early life stages of the Eastern Kamchatka population of Walleye pollock, a key species for Russian fisheries. Its spawning occurs mainly in the deep-sea canyons of Avacha and Kronotsky Bays. This study aims to describe the methodology developed to investigate the impact of tidally driven hydrophysical processes on pollock egg distribution, with a focus on its application in the deep-sea canyons of Avacha Bay. Two experiments were conducted in the "Central" and "Northern" canyons during the peak of pollock spawning in April 2024, coinciding with the spring tide when tidal effect on the environment is maximized. The experimental methodology was based on frequent hydrological profiling and layer-by-layer sampling of ichthyoplankton, carried out over a day. The study identified a 50-meter amplitudes of vertical oscillation of the thermocline, located at 320–420 meter between warm and cold intermediate layers, with a distinct diurnal rhythm in the "Central" canyon and semidiurnal one in the "Northern" canyon. These results highlight the critical role of tidal dynamics in shaping hydrophysical variability, which in turn potentially affects pollock eggs vertical redistribution and development in the deep-sea canyons of Avacha Bay.

Ключевые слова: vertical water structure, tides, internal tidal waves, distribution of pollock eggs, deep-sea spawning areas, canyons of Avacha Bay, Pacific Ocean, FESOM-c

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© *А. А. Коник*[1*], *А. В. Зимин*[1,2], *О. А. Атаджанова*[1,3], *Е. И. Свергун*[1], *Д. А. Романенков*[1], *Е. В. Софьина*[1,4], *А. И. Варкентин*[1,5], *О. Б. Тепнин*[1,5], *Д. Я. Саушкина*[1,5], 2024
© Перевод с русского: *Е. С. Кочеткова*, 2024
[1]Институт океанологии им. П.П. Ширшова РАН, 117997, Нахимовский проспект, д. 36, г. Москва
[2]Санкт-Петербургский государственный университет, 199034, Университетская наб., д. 7–9, г. Санкт-Петербург
[3]Морской гидрофизический институт, 299011, ул. Капитанская, д. 2, г. Севастополь
[4]Российский государственный гидрометеорологический университет, 192007, ул. Воронежская, д. 79, г. Санкт-Петербург

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[5]Камчатский филиал ГНЦ РФ ФГБНУ «ВНИРО», 683000, ул. Набережная, д. 18, г. Петропавловск-Камчатский
*konikrshu@gmail.com

ВНУТРИСУТОЧНАЯ ИЗМЕНЧИВОСТЬ ВЕРТИКАЛЬНОЙ СТРУКТУРЫ ВОД И РАСПРЕДЕЛЕНИЯ ИКРЫ МИНТАЯ В ГЛУБОКОВОДНЫХ КАНЬОНАХ АВАЧИНСКОГО ЗАЛИВА: НАТУРНЫЙ ЭКСПЕРИМЕНТ В ПЕРИОД НЕРЕСТА

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Аннотация

На шельфе и континентальном склоне Тихого океана вдоль полуострова Камчатка приливная динамика является значимым, но недостаточно изученным фактором формирования изменчивости гидрологической структуры вод. Эта изменчивость влияет на распределение ранних стадий развития важнейшего объекта отечественного промысла — восточнокамчатскую популяцию минтая, основной нерест которого происходит в глубоководных каньонах Авачинского и Кроноцкого заливов. Целью статьи является описание особенностей разработанной методики натурного эксперимента по изучению влияния гидрофизических процессов, обусловленных приливом, на распределение икры минтая и краткое представление ее применения в рамках экспедиционных работ в глубоководных каньонах Авачинского залива. В рамках исследования были проведены два специализированных эксперимента в «Центральном» и «Северном» каньонах в апреле 2024 г. в сроки, близкие к пику нереста минтая. Даты выполнения измерений выбирались в период сизигийного прилива, когда влияние приливной динамики на характеристики среды максимально. Методика экспериментальной работы основывалась на учащенных гидрологических измерениях и послойных обловах ихтиопланктона, выполнявшихся в разные фазы прилива за период более суток. В работе представлены результаты профилирования в привязке к данным моделирования приливной динамики. Установлено, что амплитуда колебания глубоководного термоклина между теплым и холодным промежуточными слоями, залегающего на глубине 320–420 м, составляет около 50 м и имеет выраженный суточный период — в «Центральном» каньоне — и полусуточный — в «Северном» каньоне. По данным измерений описана изменчивость распределения икры минтая в зависимости от колебания термоклина. Представленные результаты показывают значимость приливной ритмики в изменчивости гидрофизических процессов, которые потенциально влияют на перемещения икры и её развитие в глубоководных каньонах Авачинского залива.

Ключевые слова: вертикальная структура вод, прилив, внутренние приливные волны, распределение икры минтая, районы глубоководного нереста, каньоны Авачинского залива, Тихий океан, FESOM-C

1. Introduction

Walleye pollock (*Gadus chalcogrammus*) is a key pelagic species in the northern Pacific Ocean ecosystem and a critical resource for both domestic and global fisheries. By global catch volume, pollock ranks second only to Peruvian anchoveta [1]. One of the largest populations of this species, the Eastern Kamchatka population, inhabits the Pacific waters adjacent to the Kamchatka Peninsula [2]. A primary spawning area for this population is the deep-sea canyons of Avacha Bay, where spawning occurs predominantly below 300 meters. This depth-specific spawning behavior is an adaptation to the quasi-stationary hydrological conditions characteristic of these localized areas. These canyons also support the retention of macroplankton, which serves as a vital food source for pollock larvae during their transition to exogenous feeding [3]. Eggs released in the canyons hatch into pre-larvae at depths around 180 meters [4]. As the larvae develop, they ascend to the surface layers, leaving the protective confines of the canyons and becoming subject to current-driven transport. Favorable currents either retain the larvae within the canyon system or transport them into the shelf zone [5]. However, transport to the open ocean is considered unfavorable.

The development and survival of early walleye pollock life stages largely depend on the thermodynamic conditions of the environment [6]. These conditions are shaped by the severity of the preceding autumn-winter cooling, which determines the intensity of vertical mixing; the structure of the main stream of the cold Kamchatka Current; and the characteristics of spring warming and wind-driven mixing. In April, these combined processes create a three-layered water structure: a thin spring warming layer (2–3 °C) a few meters thick; beneath it, a cold intermediate layer (CIL) with anomalously low temperatures (down to –1 °C) up to 400 m thick; and, further below, a warm intermediate layer (WIL) with core temperatures of 3–3.2 °C and a thickness of about 100–150 m. Pollock spawning occurs primarily at the boundary between the CIL and WIL, at depths of 200–500 meters [4]. This boundary exhibits significant interannual, seasonal, and short-term variability.

For example, daily observations conducted in 2006 in one of the deep-sea canyons of Avacha Bay revealed vertical oscillations of the thermocline between these layers, with an amplitude of 50 meters and a period of approximately half a day. Based on these findings, the authors hypothesized that these relatively short-period thermocline oscillations, likely associated with internal waves, could influence pollock egg transport. Vertical displacements may be critical for early fish stages, as a rise or descent of eggs by several tens of meters within a few hours could directly increase their mortality.

The impact of internal waves, including tidal waves, on ichthyoplankton redistribution has been addressed in a limited number of studies. In 1982 [7], the use of tracers placed in regions of surface manifestations of internal waves demonstrated their potential effect on plankton transport. While surface tracers sometimes showed no net horizontal displacement, in other cases, they shifted 1–2 km shoreward within a few hours. In 2009 [8], trawl-acoustic surveys revealed the influence of tidal oscillations on the distribution of ichthyoplankton and adult fish inhabiting a shallow bank near the Gulf of Maine in the Atlantic Ocean. Since then, numerous field experiments and modeling studies, summarized in [9], have shown that internal waves affect the local habitats of coastal marine organisms, either by vertical displacement or through the advection of water masses with differing properties. The direction and magnitude of transport experienced by passive drifting organisms in internal waves depend on their depth and ability to migrate vertically. It is noteworthy that linear internal waves alone are unlikely to cause significant organism transport. Instead, they may facilitate exposure to currents that carry the organisms beyond favorable development zones for eggs and larvae. According to [10], a persistent semidiurnal internal tidal wave observed in the upper part of the Monterey Submarine Canyon generates regular internal bores that transport cold, nutrient-rich subthermocline waters onto the adjacent shelf, fueling primary production. These moving hydraulic jumps (internal bores) can also carry pelagic fish larvae beyond the canyon boundaries. It is noteworthy that linear internal waves alone are unlikely to cause significant organism transport. Instead, they may facilitate exposure to currents that carry the organisms beyond favorable development zones for eggs and larvae. According to [10], a persistent semidiurnal internal tidal wave observed in the upper part of the Monterey Submarine Canyon generates regular internal bores that transport cold, nutrient-rich subthermocline waters onto the adjacent shelf, fueling primary production. These moving hydraulic jumps (internal bores) can also carry pelagic fish larvae beyond the canyon boundaries. In contrast, nonlinear (short-period) internal waves, which are common in Avacha Bay [11], can cause significant horizontal transport of passive particles, unlike linear waves. Evidence of the continuous presence of nonlinear internal waves in the study area has been obtained from in situ observations [12] conducted both in the deep-water regions of Avacha Bay and on the shelf near Cape Shipunsky. Insights into the characteristics and persistent occurrence of these waves have been expanded through year-round satellite observations [13]. As shown in [14], the most likely mechanism for generating nonlinear internal waves is the transformation of internal tides. This finding indirectly supports the hypothesis that the tide driven hydrological processes may significantly affect pollock eggs distribution in deep-sea canyons. It is hypothesized that these processes may expose pollock eggs to unfavorable conditions, potentially leading to increased mortality. Eggs loss varies across the individual canyons of Avacha Bay and between years [15]. Consequently, investigating local dynamic factors influencing pollock distribution during early developmental stages is a priority for understanding the mechanisms that shape the recruitment success of this species.

To test this hypothesis, a comprehensive experiment combining simultaneous high-frequency hydrological and ichthyological observations is required. The methodological framework must account for the specific challenges of working on the continental slope in a region with highly complex hydrometeorological conditions. This approach should enable the coverage of significant depths while also providing detailed insights into the variability of hydrophysical fields and plankton communities on small spatial and temporal scales. It is worth noting that current practices in fisheries oceanography [6, 16] are primarily designed to monitor variability at larger scales than those discussed here. Variability associated with tidal processes remains outside the scope of such studies.

The objective of this study is to describe the features of a newly developed methodology for field experiments aimed at investigating the influence of tidal hydrophysical processes on the distribution of pollock eggs. Additionally, the study provides a brief overview of preliminary results obtained from work conducted in the canyons of Avacha Bay in April 2024.

2. Methodology of the Field Experiment

The main goal of the field experiment in Avacha Bay was to collect hydrological and ichthyological data using standard instruments with minimal ship time. The analysis of these data serves both the purposes of standard fisheries monitoring and the quantitative assessment of short-period (diurnal) variability in the vertical structure of thermohaline fields and the distribution of early life stages of pollock during the spawning period, with reference to the characteristics of the tidal cycle.

The epicenters of pollock spawning in Avacha Bay are located in the deep-sea canyons, including the so-called "Northern" and "Central" canyons (see Fig. 1a). Over the past 20 years, specialists from KamchatNIRO have conducted work at monitoring stations located at the canyon heads during the spring months, throughout the entire spawning period, whenever possible [6]. The locations of these stations determined the areas for the field experiment.

The timing of the work in the canyon area was determined in advance, taking into account both the dates of the mass pollock spawning (April) and the anticipated significant role of tidal processes. Tidal dynamics in Avacha Bay were assessed based on the results of model calculations (regional FESOM–C model) using a high spatial resolution computational grid [17], which previously showed good accuracy when compared with tide gauge data. The modeling results also revealed significant differences between the calculated tidal currents and estimates from global models. Therefore, the dates for conducting the experiment within the expected spawning period were selected during the spring tide, when the impact of tidal dynamics on environmental characteristics is maximal (see Fig. 1b).

The work was divided into four stages. The first and fourth stages involved standard (monitoring) studies: profiling of thermohaline parameters, ichthyoplankton sampling from 500 m to the surface, followed by stratified sampling for the following depth horizons: 0–25, 25–50, 50–100, 100–200, 200–300, 300–400, 400–500 m. The second stage focused on assessing the features of the hydrological structure of the waters based on vertical temperature profiles, determining the boundary between the cold intermediate layer (CIL) and warm

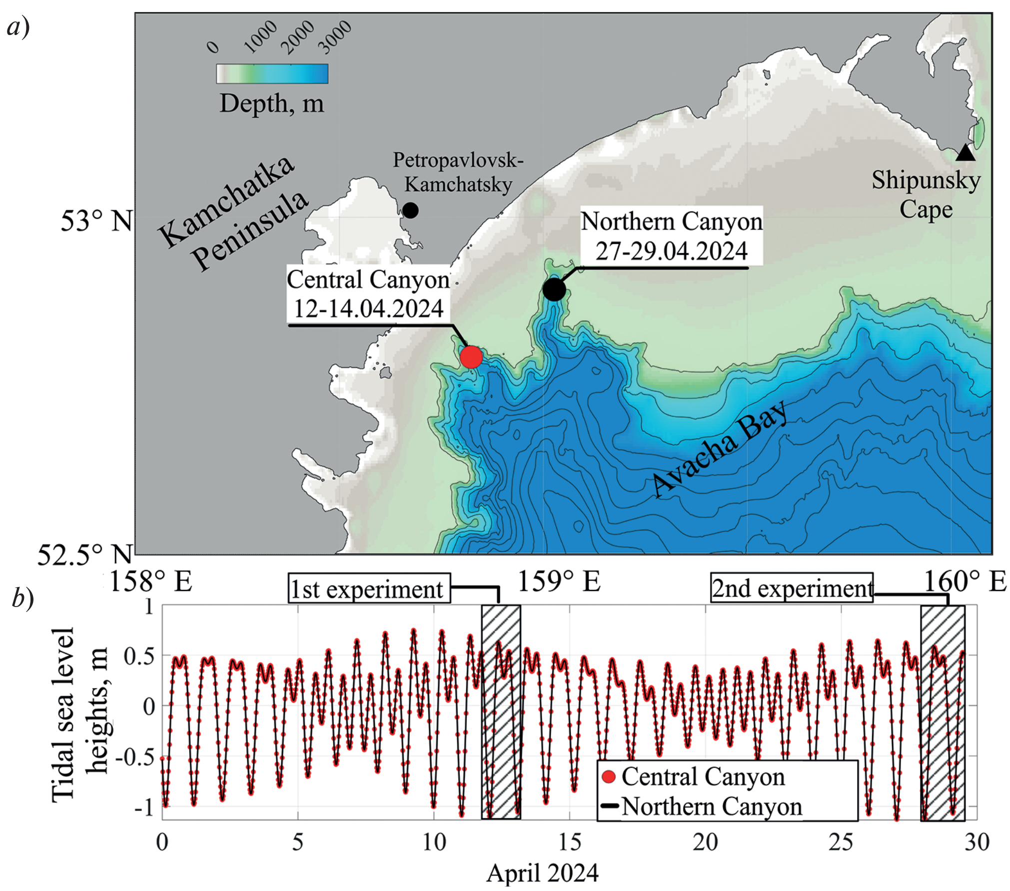

Fig. 1. Bathymetric map of Avacha Bay, red and black dots indicate the positions of the "Central" and "Northern" canyons with the dates of in-situ experiments (*a*); tidal sea level heights according to the FESOM-c model [17] are provided at these dotes in April 2024. The shaded areas in Figure 1b correspond to the periods of experiments in the "Central" (1st experiment) and "Northern" (2nd experiment) canyons (*b*)

intermediate layer (WIL), and using the Brent-Väisälä frequency profile to solve the Sturm-Liouville problem [18] to determine the positions of vertical velocity maxima for the first and second modes of internal waves and the vertical distribution of early life stages of pollock (depth horizons with the highest egg concentrations were identified based on stratified sampling). The obtained estimates were used to select horizons for high frequent eggs sampling. The third stage, lasting at least one day, involved high-frequency comprehensive stations, which included hydrological measurements and ichthyoplankton sampling at the selected horizons with a time interval of two hours. The work was conducted at the same coordinates for each canyon at depths greater than 550 m. Based on the results of these measurements, the diurnal variability of the CIL-WIL boundary position and the eggs concentration at the selected horizons were assessed.

Temperature and salinity profiling was conducted using an STD-48 (Sea Sun Technology, Germany) probe with a measuring interval of at least 0.5 m in depth. Ichthyoplankton sampling was performed using an ichthyoplankton conikal net ICN-80 with an ascent rate of 0.5 m/s. The collected plankton samples were preserved in a 4 % formaldehyde solution for subsequent laboratory processing. In the laboratory, the ichthyoplankton was separated from the total plankton sample, and its species composition was identified, with a focus on the early developmental stages of pollock. The number of eggs, larvae, and juveniles was counted, and the developmental stages of the embryos were determined using the D. Blood scale and co-authors [19]. According to D. Ya. Saushkina and co-authors [20], using the scale from [19] for determining the developmental stages of pollock, provides more accurate ecological insights into pollock spawning and daily egg production than the T.C. Rass scale [21], adapted for pollock by N.N. Gorbunova [22]. Stage 1 of this scale by D. Blood and co-authors [19] at a water temperature of 1–2 °C (the average water temperature at which egg development occurs in the canyons of Avacha Bay) corresponds to an embryo age of approximately 3 hours.

3. Peculiarities of the field experiments

Fieldwork in the head of “Central” canyon was conducted from April 12 to 14, and in the “Northern” canyon from April 27 to 29, 2024, aboard the research vessel “Engineer Martynov” (KamchatNIRO). In both cases, the experiment period coincided with the maximum tidal forcing in the spring-neap cycle (see Fig. 1b). All work was conducted according to the methodologies described above. During each experiment, 17 comprehensive (hydrological and ichthyoplankton) stations were carried out. The only deviation from the work program due to navigational requirements was the cancellation of repeated layer-by-layer plankton sampling at depths of 0–200 meters in the “Northern” canyon. The following primarily focuses on the results of hydrological observations, while the results of layer-by-layer plankton sampling will be discussed in detail in subsequent works.

The weather conditions during the experimental periods were challenging. During the work in the “Central” canyon, the synoptic conditions were influenced by a low-gradient baric field, and strong winds were not observed. However, swell waves of up to 0.7 m in height were noted, coming from the open ocean. During the work in the “Northern” canyon, atmospheric processes were driven by the approach of a large cyclone. Overcast weather prevailed with precipitation in the form of wet snow and rain. The wind and swell steadily intensified, and by the end of the work, wave heights reached 1 m.

The results of temperature and salinity profiling during the first stage of the experiments, conducted in the “Central” and “Northern” canyons, are presented in Fig. 2.

In the “Central” canyon (see Fig. 2a), a thin layer of warm, freshened water was observed at the surface. Beneath it, up to a depth of 320 m, relatively cold waters (CIL) were present. The absolute minimum temperature was observed in the 10–20 m layer, at 0.4 °C. Deeper in the CIL, there was a monotonic increase in both temperature (up to 1.2 °C) and salinity (up to 33.2 psu). Below, there was a region approximately 100 m thick, where the temperature gradient increased to an average of 2 °C/100 m, and below 400 m, warm waters of the WIL were present (above 3 °C). Modal analysis (see Fig. 2c) showed a maximum vertical speed for the first mode of internal waves at the 320 m horizon. According to the results of the layer-by-layer plankton trawls conducted on April 12, detailed discussion of which will be provided in subsequent papers, more than two-thirds of all embryos were located in the layer above 300 m, and the maximum amount of eggs (46.2 %) was found in the 200–300 m layer. Therefore, for the daily layer-wise trawls during the third stage of the experiment in the “Central” canyon, the horizons of 250–300 m and 300–350 m were selected.

In the “Northern” canyon (see Fig. 2b), a thicker warm layer (around 2 °C) and relatively fresh water (31.9 psu) were observed at the surface. Below, the CIL was observed with its core at 100 m and a temperature

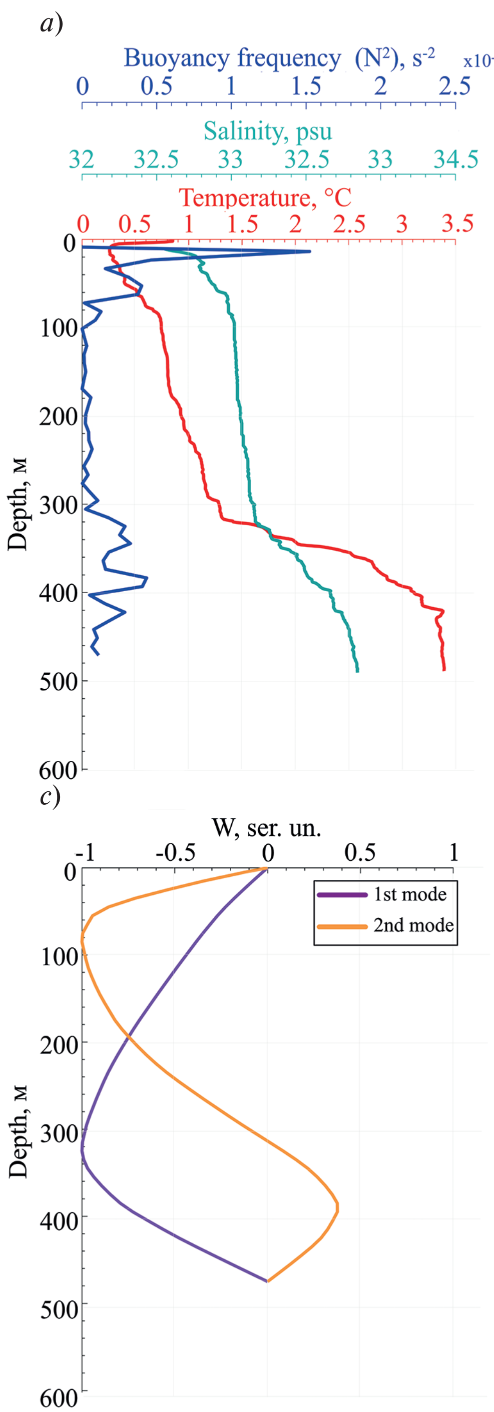

Fig. 2. Vertical variability of seawater temperature, salinity and buoyancy frequency for the "Central" (*a*) and "Northern" canyons (*b*) of Avacha Bay; the vertical velocity eigenfunctions (W) of 1st and 2nd internal waves modes in the "Central" (*c*) and "Northern" (*d*) canyons

below 1 °C. With depth, the temperature (and salinity) in this layer increased slowly, reaching about 1 °C (33.1 psu) at 400 m. Further down there was a sharp layer between the CIL and WIL where temperature and salinity. This layer extended down to a depth of 420 m. The boundary between the CIL and WIL was most clearly expressed at horizons from 400 to 420 m. Below, the temperature reached over 2.5 °C, and salinity was 33.5 psu. Modal analysis (see Fig. 2d) showed a maximum in vertical speeds for the first mode of internal waves around 400 m. According to the results of layer-by-layer plankton trawls conducted on April 27, about 72 % of all pollock embryos were found in the 400–500 m horizon. As a results during the third stage of the experiment in the "Northern" canyon, the horizons of 400–450 m and 450–500 m were selected for the layer-by-layer trawls.

4. Results of the experiments

4.1. Variability of hydrological fields

An understanding of the variability of water temperature in the "Central" canyon during the tidal cycle can be obtained from the data of synchronous temperature observations and computed total tidal current vectors, as shown in Figure 3. It is worth noting that according to modeling of individual tidal harmonics (semidiurnal M2 and diurnal K1), the current ellipses were predominantly oriented across the axis of the "Central" canyon and along the axis of the "Northern" canyon: the magnitude of diurnal tidal currents was several times greater than the magnitude of semidiurnal currents [17]. Accordingly, the calculated total tide from 12 components corresponds to an irregular diurnal type. During the experiment the total tidal range was about 1.5 m and barotropic tidal currents velocity reached 12.5 cm/s. The maximum current speeds were observed in the direction along the continental slope during the ebb phase. At the same time, currents during the tide phase were an order of magnitude weaker and directed towards the shelf.

During the experiment the water temperature in the "Central" canyon in the CIL ranged from 0.4 to 1 °C, while in the WIL it ranged from 2.8 to 3.6 °C. The maximum uplift of WIL waters and the thermocline separating the WIL from the CIL occurred during the peak of tidal current speeds, as well as when the tidal current was directed southwest, i. e., primarily across the canyon axis. In contrast, the thermocline deepened during the minimum of tidal currents. Maximum temperature gradient between WIL and CIL roughly corresponded to the depth of the 1.5 °C isotherm. The amplitude of the vertical displacement of the sharp gradient layer reached 50 m.

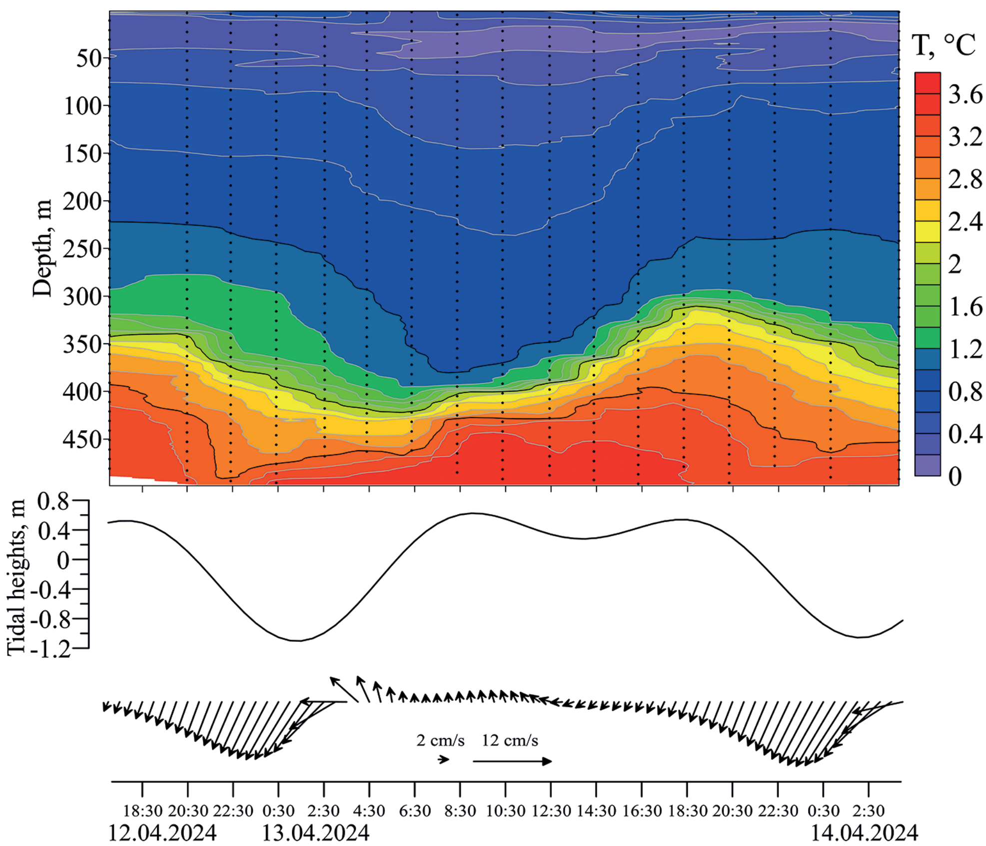

Fig. 3. Results of in situ measurements during the experiment in the "Central" canyon from April 12–14, 2024, combined with the tidal heights (black line) and barotropic tidal currents (black arrows) according to [17]. Vertical rows of points indicate CTD measurements

Furthermore, temperature fluctuations were observed in the CIL core, with the depth of its lower boundary fluctuating with amplitude of 20 m. Although, as noted earlier the temperature variability in this layer was minimal, approximately 0.5 °C.

Overall, the fluctuations in tidal level and the lower boundary of interface between CIL and WIL coincide. The minimum depths of its immersion correspond to the maxima of tidal current speed, which suggests the formation of a forced or trapped tidal internal wave with about diurnal period in the canyon.

An understanding of the variability of water temperature in the "Northern" canyon during the tidal cycle can be obtained from synchronous temperature observations and calculations of the characteristics of barotropic tidal currents, as shown in Figure 4. The total tide here also belongs to the irregular diurnal type, and the fluctuations in the water level are very similar to those described earlier. During the observation period, the total range of level fluctuations was just over 1.5 m, and tidal current speeds reached 12.5 cm/s. The maximum current speeds were also observed during the ebb tide along the canyon axis. During the tide phase the currents were somewhat weaker than ones during the ebb phase, in contrast as it was observed in the "Central" canyon. The tidal flow directed towards the shore was shorter in duration than one from the shore.

During the study in the "Central" canyon, the sea surface temperature fluctuated depending on the time of day, ranging from 2.2 to 1.7 °C. The CIL core had temperature less 0.5 °C and significant fluctuations of the position of lower boundary CIL were experienced. This boundary could shift by tens of meters over the course of several hours. Overall, the water temperature in the CIL ranged from 0.2 to 1.4 °C. The boundary between the CIL and WIL was quite clearly defined at depths around 400 meters, and the maximum gradient was observed at the depth of the 2.5 °C isotherm. This isotherm underwent irregular semi-diurnal fluctuations with an amplitude ranging from 20 to 50 meters.

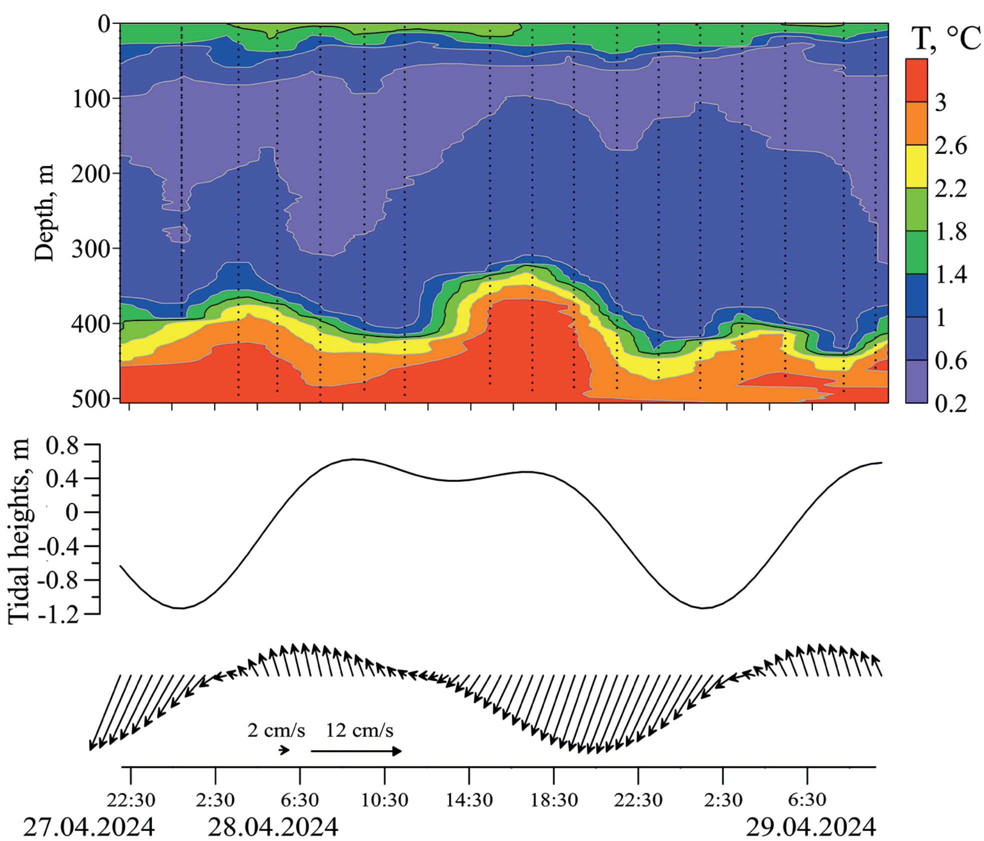

Fig. 4. Results of in situ measurements during the experiment in the "Northern" canyon from April 27–29, 2024, combined with the tidal heights (black line) and barotropic tidal currents (black arrows) according to [17]. Vertical rows of points indicate CTD measurements

In general, a connection can be observed between the fluctuations of tidal currents and the lower boundary of the water layer associated with the core of the CIL. Impact of northwest currents directed towards the shelf manifests in an increase in the thickness of the water column of the CIL. The situation changes with southwestward currents. With a small time delay after the maximum current speeds, a deepening of the CIL-WIL boundary was observed. The periods during which the minimum depths of the thermocline were recorded corresponded to the maximum tidal current speeds. Two hypotheses can be proposed regarding the mechanism behind these fluctuations, which repeat during the tidal cycle, both of which require further verification. The first hypothesis suggests that a tidal internal wave reflects from the bottom near the observation point, leading to its decay. The second hypothesis suggests that when the direction of the tidal current changes, the internal hydraulic jump formed at the canyon's head begins to break down.

4.2. Variability in the Pollock eggs distribution

According to the results of the work conducted on April 12 in the "Central" canyon, 9,714 pollock eggs were recorded per square meter during laboratory processing. All embryos were at developmental stages 1–13, with stage 9 being the dominant one (25 %). Considering that the majority of the eggs were at early developmental stages, it can be assumed that the experiment coincided with a time close to the peak of the species' reproduction in this canyon. According to the results of the trapping conducted on April 27 in the "Northern" canyon, 5,020 pollock eggs were recorded per square meter. The samples predominantly contained embryos at stages 6 (22.0 %) and 14–17 (48.0 %). The predominance of eggs at later developmental stages indicates that by the time of the experiment, the peak of Pacific pollock spawning in the "Northern" canyon was coming to an end.

The results of the field experiment on the temporal variability of the total number of pollock eggs and embryos at stage 1 of development at specific depths, and fluctuations of isotherms corresponding to the boundary between the CIL and WIL in the "Central" and "Northern" canyons are presented in Fig. 5.

As seen in Fig. 5a-b, the fluctuations in the amount of spawned pollock eggs in the "Central" canyon predominantly follow a daily rhythm. The maximum amount at both sampled horizons was recorded at 16:30 on April 13. At this time, there was an upward shift in the upper boundary of the WIL and extremely weak tidal currents. The minimum was observed 12 hours earlier, corresponding to the minimum depth of the sharp layer between CIL and WIL as the current direction shifted. It is worth noting that the increased spawning (abundance of eggs at the 1st developmental stage) above CIL boundary was mainly observed under conditions of weak tidal currents and an intensifying vertical temperature gradient from 12:30 to 16:30 on April 13. Under conditions of intensified tidal currents and weakened vertical temperature gradients, the amount of eggs was less.

Analysis of the catch results in the "Northern" canyon (see Fig. 5c-d) showed the absence of clearly defined peaks as seen in the previous experiment. The maximum number of recorded eggs did not correspond to the peak of their reproduction. A significant portion of the eggs was caught in the morning, while the peak of the 1st developmental stage occurred in the evening and nighttime, which requires further investigation. It is noteworthy that the maximum total number of eggs, and eggs at the 1st developmental stage was observed when the WIL deepened and the vertical gradients at its boundary weakened, corresponding to the rearrangement and weakening of tidal currents. Spawning occurred predominantly at the upper boundary of the WIL.

5. Conclusion

The vertical variability of water structure and egg distribution in the deep-sea canyons of Avacha Bay exhibits significant dynamics. Three-layer water structure in the spring is a characteristic feature of this region and this was once again confirmed through high-frequency profiling. Temperature in the identified layers generally aligns with one on early data [6]: the CIL temperature fluctuated between 0.5–1 °C, and that of the WIL between 2.5–3.5 °C. The average thickness of the cold layer was 200 meters, while the warm layer averaged 100 meters. Notably, some specifics were observed. Namely, in the "Central" canyon the thickness of the CIL, with an average temperature of about 0.8 °C, was 200 meters, while in the "Northern" canyon, it was 300 meters with an average water temperature of 0.5 °C. The characteristics of the WIL also varied: in the "Central"

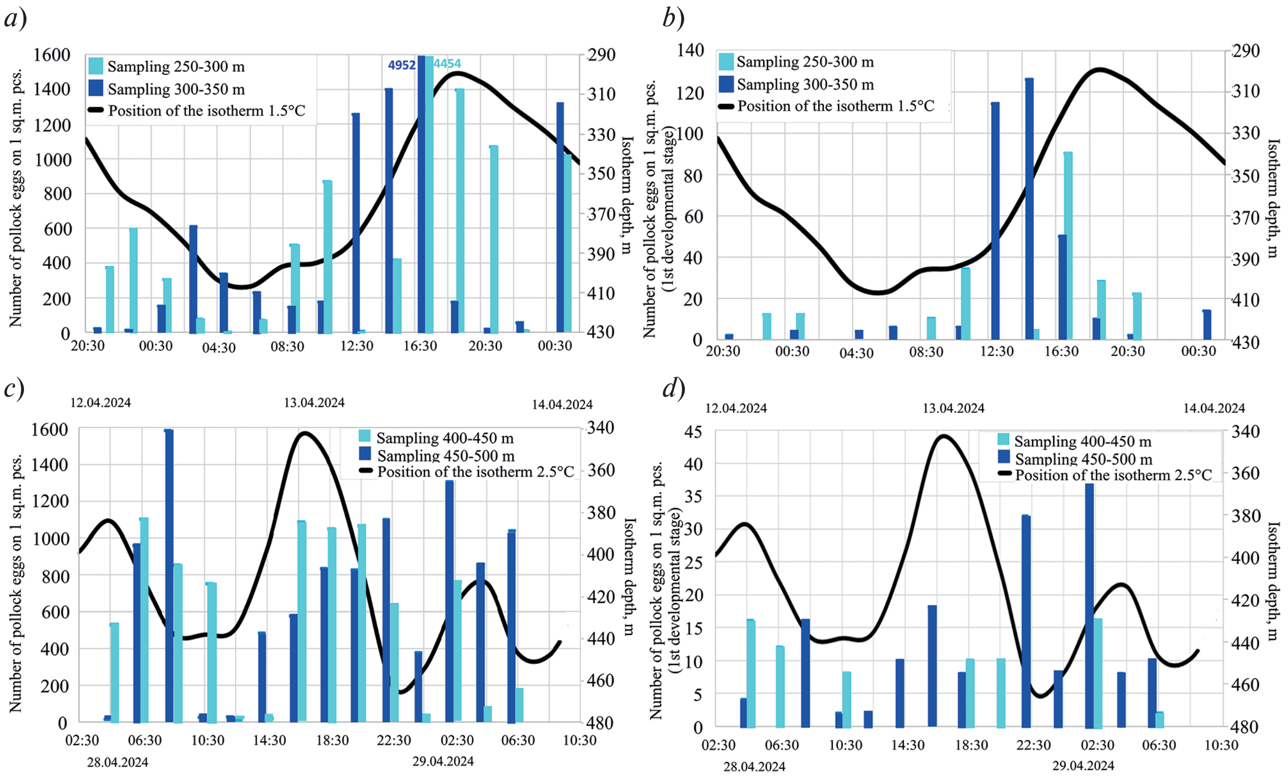

Fig. 5. Number of pollock eggs in two layers and isotherm position between cold intermediate layer and warm intermediate layer during the experiment period: *a* – total numder of eggs and 1.5 °C in the "Central" canyon; *b* – number of eggs at the 1st developmental stage and 1.5 °C in the "Central" canyon; *c* – total number of eggs and 2.5 °C in the "Northern" canyon; *d* – number of eggs at the 1st developmental stage and 2.5 °C in the "Northern" canyon. The blue and cyan figures in Fig. 5a show the maximum number of pollock eggs at 16:30

canyon, its temperature was 3.5 °C, while in the "Northern" canyon, it was 2.5 °C. The amplitude of the CIL-WIL boundary fluctuation, based on observations, was about 50 meters and followed a distinct diurnal period in the "Central" canyon and an irregular semidiurnal one in the "Northern" canyon.

The quantitative estimates of eggs obtained during the experiments indicate that the first experiment coincided with a period close to the peak of the species' reproductive cycle in this canyon, which aligns well with earlier estimates [16]. The second experiment, on the other hand, took place at the end of the spawning period. The overall comprehensive results of the experiments show that a relationship between the fluctuations of the cold and warm intermediate layer boundaries, influenced by tidal processes, and the number of eggs in general is evident. However, in some cases, the fluctuation in egg number occurs with a slight delay relative to the fluctuations of the characteristic isotherm between the layers. This delay is likely due to the neutral buoyancy of the embryos, which requires only a small impulse to raise or lower them at the CIL-WIL boundary. Additionally, the lowering of the ichthyoplankton net and profiling were not done simultaneously, but with a slight delay of 15–30 minutes.

The quantitative estimates of walleye pollock eggs obtained during the experiments indicate that the first experiment coincided with a period close to the peak of the species' reproductive cycle in this canyon, which aligns well with earlier estimates [16]. The second experiment, on the other hand, took place at the end of the spawning period. The overall comprehensive results of the experiments show that a relationship between the fluctuations of the cold and warm intermediate layer boundaries, influenced by tidal processes, and the amount of eggs in general is evident. However, in some cases, the fluctuation in egg numbers occurs with a slight delay relative to the fluctuations of the characteristic isotherm between the layers. This delay is likely due to the neutral buoyancy of the embryos, which requires only a small impulse to raise or lower them at the CIL-WIL boundary. Additionally, the lowering of the ichthyoplankton net and the profiling were not done simultaneously, but with a slight delay of 15–30 minutes.

Further research will focus on a deeper analysis of the experimental results, incorporating remote sensing data and internal wave modeling results.

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About the Authors

KONIK, Aleksandr A., researcher of St. Petersburg Branch of Shirshov Institute of Oceanology of RAS, Cand. Sc. (Geogr.), SPIN-code (РИНЦ): 5839–1738, ORCID: 0000-0002-2089-158X, Scopus AuthorID: 57203864647, WoS ResearcherID: AAB-7195–2020, e-mail: konikrshu@gmail.com

ZIMIN, Aleksey A., chief scientific researcher of St. Petersburg Branch of Shirshov Institute of Oceanology of RAS, Dr. Sc. (Geogr.), SPIN- code (РИНЦ): 9833-3460, ORCID: 0000-0003-1662-6385, Scopus AuthorID: 55032301400, WoS ResearcherID: C-5885–2014, e-mail: zimin2@mail.ru

ATADZHANOVA, Oksana A., senior researcher of St. Petersburg Branch of Shirshov Institute of Oceanology of RAS, Cand. Sc. (Geogr.), SPIN-code (РИНЦ): 5016-2970, ORCID ID: 0000-0001-6820-0533, Scopus AuthorID: 57188718743, WoS ResearcherID: R-7835-2018, e-mail: oksanam07@list.ru

SVERGUN, Egor I., researcher of St. Petersburg Branch of Shirshov Institute of Oceanology of RAS, Cand. Sc. (Geogr.), SPIN-code (РИНЦ): 3212-7041, ORCID ID: 0000-0002-9228-5765, Scopus AuthorID: 57195066881, WoS ResearcherID: AAC-7289-2020, e-mail: egor-svergun@yandex.ru

ROMANENKOV, Dmitriy A., leading researcher of St. Petersburg Branch of Shirshov Institute of Oceanology of RAS, Cand. Sc. (Geogr.), SPIN-code (РИНЦ): 4872-3349, ORCID: 0009-0005-0374-486X, Scopus AuthorID: 6506855768, WoS ResearcherID: U-8280-2017, e-mail: dmromanenkov@yandex.ru

SOFINA, Ekaterina V., leading researcher of St. Petersburg Branch of Shirshov Institute of Oceanology of RAS, Cand. Sc. (Phys.-Math.), SPIN-code (РИНЦ): 8904-4934, ORCID: 0000-0001-9206-8253, Scopus AuthorID: 23111468200, WoS ResearcherID: E-3920-2014, e-mail: sofjina_k@mail.ru

VARKENTIN, Alexandr I., leading researcher of KamchatNIRO, Cand. Sc. (Bio.), SPIN-code (РИНЦ): 6126-6033, ORCID: 0000-0002-1735-0088, WoS ResearcherID: ADK-2588-2022, e-mail: a.varkentin@kamniro.vniro.ru

TEPNIN, Oleg B., researcher of KamchatNIRO, SPIN-code (РИНЦ): 4002-1975, ORCID: 0000-0001-9596-4336, WoS ResearcherID: KIL-1378-2024, e-mail: tenpin@ya.ru

SAUSHKINA, Darya Ya., senior specialist of KamchatNIRO, SPIN-code (РИНЦ): 4059-2130, ORCID: 0000-0001-8913-0386, Scopus AuthorID: 57219658866, WoS ResearcherID: AAY-8161-2021, e-mail: d_melnik@rambler.ru