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Modeling the transport of East Kamchatka pollock eggs and larvae taking into account tidal dynamics

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Abstract

The work examines the drift of pollock eggs and larvae in the Pacific Ocean region adjacent to the southeastern coast of the Kamchatka Peninsula and the northern Kuril Islands. A model approach is used, combining particle trajectory calculations using the ICHTHYOP software, ocean reanalysis data, and the results of a regional tidal model. The eggs and larvae are considered as passive tracers, and their transport from the main spawning ground of the East Kamchatka pollock in the deep-water canyon of the Avacha Bay was calculated for one month in 2024 and 2025, starting from the observed spawning date in April.

The main objective of the modelling was to determine the influence of various dynamic factors on particle transport and the likely locations of their accumulation, where egg development and larval hatching may occur. Identifying these locations through ichthyoplankton surveys is very difficult. The model calculations did not take into account a number of factors related to the mortality of eggs and larvae under the influence of environmental changes and predation, larval activity during development, and other processes of physical and biological interaction. The transport of tracers after their ascent to the surface in the spawning area was analyzed using background surface currents and those averaged over the upper sea layer.

The simulation results show that the predicted horizontal particle trajectories depend not only on the different hydrodynamic conditions for the two years, but also on the consideration of tidal drift. A hypothesis has been put forward regarding the dynamic conditions favorable for the development and survival of pollock eggs and larvae, under which their drift does not lead to their transport from the shelf water into the open ocean. Potential areas of particle accumulation in coastal waters have been identified.

Keywords: Lagrange model, passive tracer, eggs and larvae drift, pollock, tidal currents, FESOM–C, ICHTHYOP, submarine canyon, the Avacha Bay, Pacific Ocean

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Моделирование переноса икры и личинок восточнокамчатского минтая с учетом приливной динамики

Статья поступила в редакцию 18.09.2025, после доработки 22.10.2025, принята в печать 18.11.2025

Аннотация

В работе изучается дрейф икры и личинок минтая в области Тихого океана, прилегающей к юго-восточному побережью полуострова Камчатка и северным Курильским островам. Используется модельный подход, сочетающий расчеты траекторий частиц программным модулем ICHTHYOP, данные океанского реанализа и результаты приливной региональной модели. Икра и личинки рассматриваются как пассивные трассеры, а их перенос из основного района нереста восточнокамчатской популяции минтая, расположенного в глубоководном каньоне Авачинского залива, рассчитывался в течение месяца 2024 и 2025 гг., начиная с наблюдаемой даты нереста в апреле.

Основная цель моделирования заключалась в определении влияния динамических факторов разной природы на транспорт частиц и вероятных мест их скопления, в которых может происходить развитие икры и выклев личинок. Выявление этих мест путем ихтиопланктонных съемок весьма затруднительно. В модельных расчетах не учитывался ряд факторов, связанных со смертностью икры и личинок под воздействием изменений среды и хищничества, активностью личинок по мере их развития и других процессов физико-биологического взаимодействия. Перенос трассеров после их подъема к поверхности в зоне нереста анализировался при использовании поверхностных и средних в верхнем слое моря фоновых течений.

Результаты моделирования показывают, что прогностические горизонтальные траектории частиц зависят не только от различных для двух лет гидродинамических условий, но и от учета приливного дрейфа. Высказано предположение о благоприятных для развития и выживаемости икры и личинок минтая динамических условиях, при которых их дрейф не приводит к выносу с шельфа в открытый океан. Определены потенциальные районы скопления частиц в прибрежных водах.

Ключевые слова: Лагранжева модель, пассивный трассер, дрейф икры и личинок, минтай, приливные течения, FESOM–С, ICHTHYOP, подводный каньон, Авачинский залив, Тихий океан

1. Introduction

The northwestern Pacific Ocean region adjacent to the Kamchatka Peninsula and the northern Kuril Islands serves as a spawning, feeding, and habitat area for many commercially important fish species. Among these, the East Kamchatka population of pollock (*Gadus chalcogrammus*) is notable for its biomass and fishery importance [1–3]. The spawning range includes deep-water spawning grounds located in the canyons of Avacha and Kronotsky bays, as well as shelf spawning areas off southeastern Kamchatka and around the northern Kuril Islands [3–5]. In Avacha and Kronotsky bays, spawning also occurs on the shelf, although its scale is small compared to deep-water spawning. Varkentin et al. [4] report that in some years, roughly 61 % of all eggs are found in the deep-water canyons, with ~44 % in the ‘Northern’ canyon of the Avacha Bay. This place can be regarded as the principal center of reproduction for this population.

Spawning in the “Northern” canyon generally occurs at depths greater than 400 m. Spawning timing varies annually, generally occurring from early March to early May, with a peak in late March–early April. The long-term mean dates are 13 March for the onset of spawning, 1 April for the peak, and 19 April for its completion [4].

The study area is characterized by specific hydrological conditions. A distinctive feature of the region is the cold Kuril–Kamchatka Current (KKC) (Fig. 1). Complex bathymetry and a variable wind regime give rise to

meanders and eddies that strongly affect the hydrological structure of the waters, which exhibit a subarctic type of stratification [6–8]. On average, water transport in the near-surface layer over the shelf and continental slope of the peninsula is directed southwestward. During the pollock spawning period, current velocities range from 5 to 45 cm/s [9]. Mesoscale eddies 70–150 km in diameter are clearly detected in infrared and visible imagery, and, according to satellite altimetry, generally propagate in the same direction [10]. Closer to the coast, within bays and on the shelf, mesoscale anticyclonic structures dominate, whereas in the deep-water area east of the KKC jet, mesoscale cyclones prevail [7, 10–12]. Field experiments conducted in the deep canyons of the Avacha Bay have revealed the presence of internal waves, likely generated by the tidal cycle [13, 4].

As in other pollock stocks, the East Kamchatka population exhibits fluctuations in abundance driven by the alternation of generations with differing recruitment strength. The productivity of these generations depends primarily on survival during the early developmental stages – eggs and larvae. Strong year classes are generally associated with ‘warm’ periods [14–20], although the mechanisms governing recruitment remain poorly understood, despite repeated attempts to identify them for different populations. For the East Kamchatka pollock, a positive correlation has been reported between the abundance of four-year-old fish, the amount of fertilized eggs, and the mean water temperature [2].

One possible mechanism influencing year-class strength involves the direction of currents over the canyon system [4]. The advection of larvae hatched within the canyons into open waters may lead to substantial losses of the developing generation. Building on this hypothesis, it has been shown that the velocity and position of the main jet of the KKC can have either a negative effect – when the jet approaches the continental slope of the Avacha Bay – or a positive one when it remains offshore [21]. When the main KKC jet weakens, a stationary anticyclonic circulation tends to form in the surface layer of the Avacha Bay, which may result in the export of eggs spawned in the canyons beyond the area favourable for development. Conversely, when the Kamchatka Current deflects strongly eastward into the ocean, a cyclonic circulation dominates in the bay. Such conditions are likely more favourable for further larval development and survival.

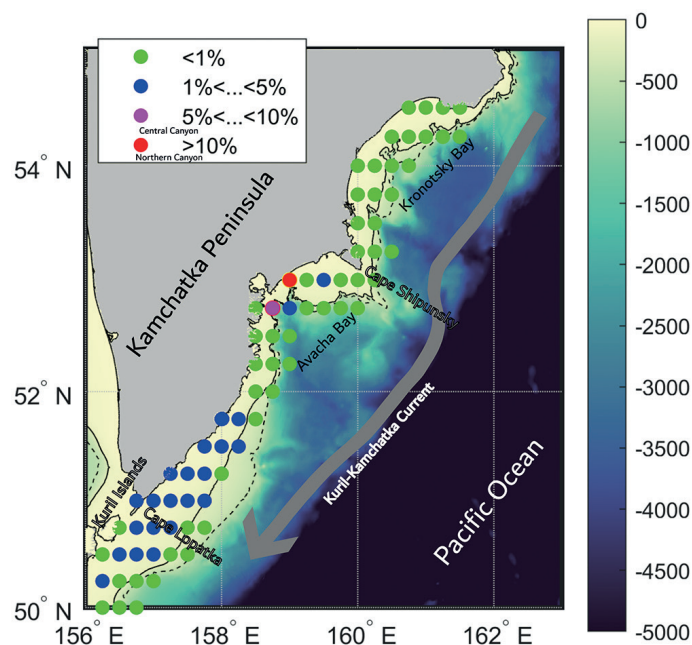


Fig. 1. Bathymetric map of the region (m) with a diagram of the main flow of the Kuril-Kamchatka Current and the average long-term distribution of the total amount of eggs caught during the spawning period (%), based on ichthyoplankton survey data. The 200-meter isobath represented by solid black line and the 500-meter isobath represented by dashed black line

Hence, understanding the direction and scale of pollock egg and larval drift, as well as the dynamic oceanic processes that control it, is essential for clarifying the mechanisms behind interannual variability in recruitment strength.

It should be noted that no direct field observations of egg drift from the deep canyons of the Avacha Bay are available; therefore, these hypotheses cannot yet be confirmed or refuted. Direct observation in natural conditions is currently unfeasible; numerical modelling is therefore the only practical method of investigation.

For this purpose, a Lagrangian approach is often employed, in which the motion of individual fluid parcels is traced through space according to the local velocity field [22]. This method enables the reconstruction of detailed structures such as eddies, circulations, and intrusions, as well as other dynamical features of the ocean, and allows the drift of particles of any origin to be quantified. In several areas of the Far Eastern Pacific, the Lagrangian framework has already been applied [22–26]; however, for the Pacific waters adjacent to Kamchatka and the northern Kuril Islands, comparable studies have not yet been conducted.

The aim of the present study is to assess, using a modelling approach, the direction and scale of pollock egg and larval drift from the deep canyon of the Avacha Bay. To this end, we addressed the following objectives::

- to examine the role of background circulation and tidal currents in the transport and dispersion of pollock eggs and larvae;
- to determine the drift trajectories of eggs and larvae originating from the deep canyon of the Avacha Bay using available data and a Lagrangian passive-particle transport model in the spring of 2024 and 2025.

2. Material and methods

Based on the considerations outlined in the Introduction, we selected the Pacific waters off southeastern Kamchatka and the northern Kuril Islands as the modelling domain for pollock egg drift, with the ‘Northern’ deep canyon of the Avacha Bay (Fig. 1) representing the spawning site. During spawning, eggs were treated as passive tracers, advected by currents of multiple origins. It was assumed that egg release occurred instantaneously at the spawning peak. Although this simplification ignores the natural decline in egg abundance over the spawning period [27], it provides a first-order approximation suitable for modelling.

Pollock spawning in the canyon during 2024 occurred from 8 March to 2 May, peaking on 4 April [4, 13]. Most eggs were released at depths of 300–400 m, though some early-stage eggs were observed between 200 and 300 m (Table). As they develop, eggs ascend due to their density contrast with the surrounding water. Reported ascent velocities vary. According to calculations in [28], assuming uniform ascent over the shelf and within the bays, the vertical drift velocity of pollock eggs ranged from 4.9 m/h (1.4 mm/s) to 8.6 m/h (2.4 mm/s), where-

as in the mesopelagic layer it is roughly an order of magnitude lower.

Moreover, vertical displacement may also be influenced by external factors. Field observations [13] indicate internal tide amplitudes at the canyon head reaching 100 m, suggesting that eggs could rise by a comparable distance within half a tidal cycle. Eggs ascending from the 200–300 m layer may thus be transported out of the canyon’s deep region. Due to the lack of reliable ascent velocity data, we assumed that, at the spawning peak, eggs had already reached the 0–200 m layer, where subsurface currents dominate their transport.

Table
 Number of pollock eggs (pcs/m²) based on stratified sampling conducted at the head of the “Northern” canyon on 4 April 2024

Layers, m	Stage of eggs development			
	1–8	9–15	16–19	20–21
0–25	2	0	0	0
25–50	6	0	0	0
50–100	14	2	0	0
100–200	478	0	0	0
200–300	6538	134	0	0
300–400	26916	4386	0	0
400–500	134	4	0	0

Simulations incorporated background and tidal currents from 4 April (spawning peak) to 2 May 2024, with the same period used for 2025 for comparison. The model did not account for biotic or abiotic factors affecting particle survival and dispersion.

2.1 Background circulation

The initial data were extracted from the operational ocean analysis and forecasting system Mercator GLOBAL_ANALYSISFORECAST_PHY_001_024¹. The product is available from 1 June 2022 to the present, with a 10-day forecast. The system implementation is GLO12v4, and the ocean model version is NEMO3.6. Spatial resolution is 1/12° (approximately 8 km) with 50 vertical levels. Bathymetry is represented by a combination of interpolated databases, ETOPO1, and GEBCO8, with ETOPO1 used for depths greater than 300 m and GEBCO8 for depths less than 200 m. The 200-m isobath approximately separates the deep-water canyons from the shelf region. For drift modelling, hourly zonal and meridional velocity components in the near-surface layer and six-hourly averages over the upper 200 m of the ocean were used on the original grid. For comparative analysis of circulation patterns across different years, monthly mean current fields were employed.

The following describes the background circulation relevant to the numerical experiments. Figure 2 shows monthly mean surface currents for April 2024 and 2025. In April–early May 2025, the KKC jet was well defined, with peak velocities of 0.75 m/s (Fig. 2b). A large anticyclonic vortex in southeastern part of domain was apparent, while no pronounced mesoscale eddies and meanders were. Velocities over the southeastern Kamchatka shelf and slope, including Kronotsky and Avacha bays, remained below 0.10 m/s, doubling locally near the the Avacha Bay shelf south of the Shipunsky Peninsula and its canyons.

In April 2024 (Fig. 2a), circulation was more complex due to reconfiguration and weakening of the KKC off southeastern Kamchatka and in Kronotsky Bay, coupled with a northward shift of the large anticyclonic vortex into the KKC jet zone. Interaction between the eddy and the KKC generated subsidiary circulations in the deep-water portion of the Avacha Bay, where currents intensified substantially, reaching peak velocities of 0.4 m/s. During some days, reorganized circulation increased background velocities over shallow shelf areas in both bays to 0.25 m/s (not shown).

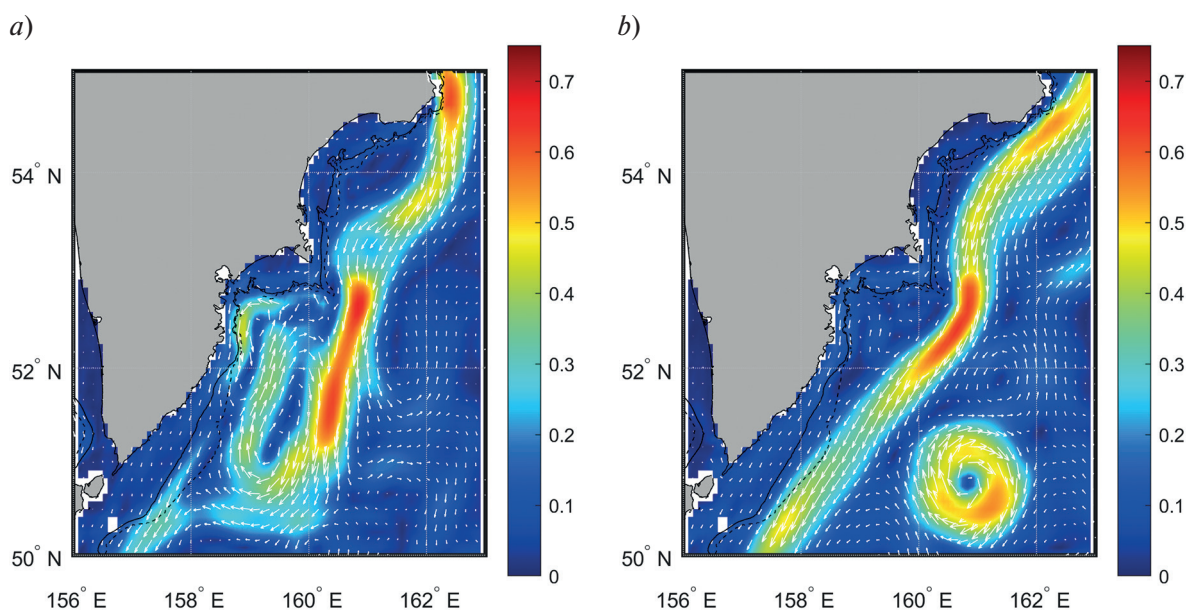


Fig. 2. Monthly mean surface currents (m/s) for the periods 4 April–3 May 2024 (a) and 4 April–3 May 2025 (b)

¹ <https://doi.org/10.48670/moi-00016>

Circulation averaged over the upper 200 m (Fig. 3) resembles surface circulation (Fig. 2) but is slightly weaker, with more diffuse boundaries between the KKC jet, eddies, and surrounding waters. In shallow areas, depth-averaging reduces current speeds by over half. Monthly averaging can also obscure some circulation features. The large southeastern anticyclonic circulation, not visible in the April 2024 monthly mean (Figs. 2a and 3a), can be tracked in daily mean fields, including its northward shift (not shown). Overall, the circulation system differs substantially between the two consecutive years, 2024 and 2025. The impact of these differences on passive tracer transport is addressed in the modelling results.

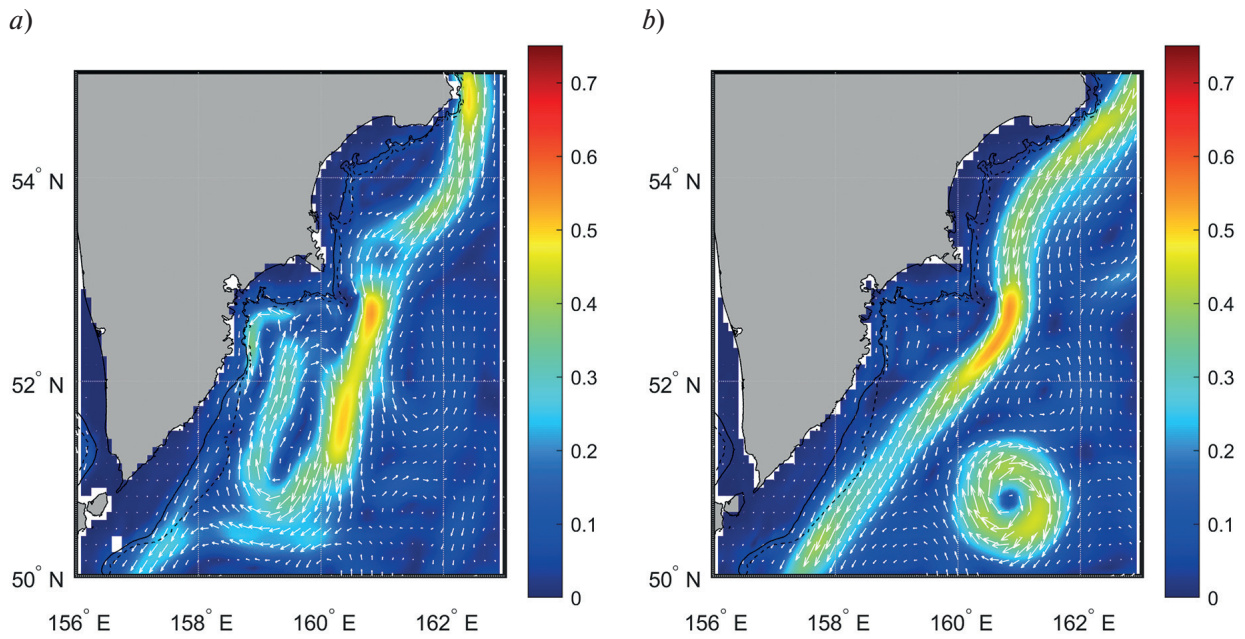


Fig. 3. Monthly mean currents (m/s) in the 0–200 m layer for the periods 4 April–3 May 2024 (a) and 4 April–3 May 2025 (b)

2.2 Tidal dynamics

Tidal currents were derived from regional simulations of barotropic tidal dynamics off southeastern Kamchatka using the finite-volume model FESOM–C [29, 30]. The model used an unstructured triangular mesh with spatial resolution adapted to local bathymetry and was validated against tide-gauge observations. Barotropic tidal velocities were computed for the entire study period, including the following constituents: M2, S2, N2, K2, K1, O1, P1, Q1, Mf, Mm, MS4, and M4. The tidal regime is mixed, with diurnal constituents predominating over semidiurnal components. Compared with global models FES2014 and TPXO9, the regional model provides a more accurate representation of tidal currents.

As reported in [30], Tidal dynamics in the Avacha Bay canyons are strongly nonlinear, with persistent residual tidal transport reaching 2 cm s^{-1} , while instantaneous tidal currents may attain 35 cm/s depending on the tidal phase (Fig. 4a). These velocities are comparable to background currents (Figs. 2 and 3) and can thus influence egg and larval drift. Residual tidal circulation – tidal currents averaged over a 29.53-day synodic month – is an order of magnitude weaker than peak velocities but exhibits characteristic along-slope transport and eddy structures (Fig. 4b). Tidal velocities were interpolated onto the GLO12v4 reanalysis space-time grid, generating a combined dataset of total circulation that includes tidal currents.

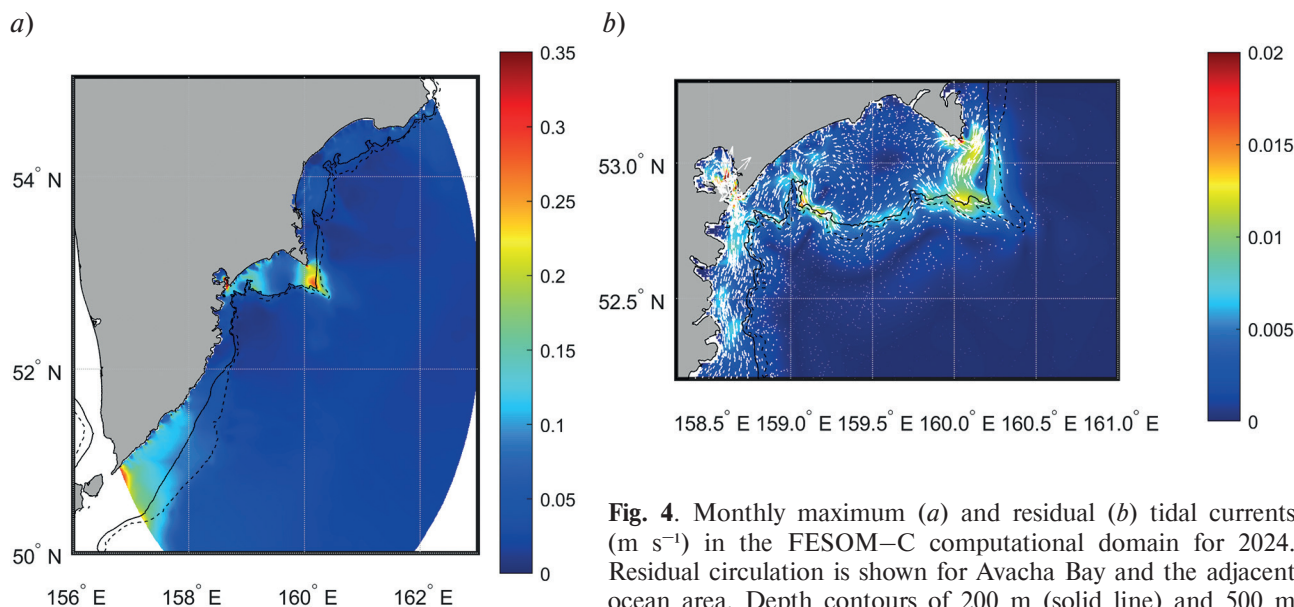


Fig. 4. Monthly maximum (a) and residual (b) tidal currents (m s^{-1}) in the FESOM–C computational domain for 2024. Residual circulation is shown for Avacha Bay and the adjacent ocean area. Depth contours of 200 m (solid line) and 500 m (dashed line) are indicated. Corresponding fields for 2025 are very similar to those for 2024 and are not shown

2.3 Drift model

The Lagrangian particle-tracking software ICHTHYOP² [31] was used to simulate the drift of passive particles. This tool computes particle trajectories in a Lagrangian framework, updating calculation parameters at each time step, which allows a more precise solution of the problem [32]. ICHTHYOP is a comprehensive model designed to investigate the influence of physical (e. g., ocean currents, temperature) and biological (e. g., growth, mortality of ichthyoplankton) factors on the drift and migration of fish eggs and larvae. The model requires time series of velocity, temperature, and salinity fields as input and offers options to specify mortality thresholds for temperature or salinity, as well as egg size and age. Its output includes detailed records of particle states and animated tracking of particle positions, with color coding to indicate properties such as age or size.

A key advantage of ICHTHYOP is its ability to incorporate three-dimensional velocity fields, including vertical velocities. However, no regional model currently provides complete vertical current information for the study area. All available reanalyses, including the GLORYS dataset used here, lack vertical circulation data. Consequently, only horizontal velocity fields were employed to address the research objectives outlined in the Introduction.

The input comprised of the previously prepared horizontal velocity fields (Sections 2.1 and 2.2). Simulation parameters were as follows: a time step of 1 h and a default background turbulence energy dissipation rate of $1\text{--}12 \text{ m}^2/\text{s}^3$. Passive particles were programmed to “bounce” back into the water upon reaching the shoreline; more complex particle–shore interaction algorithms were not considered. Various parameterizations of physical (except for horizontal background diffusion) and biological processes were not applied. The initial patch of passive tracers was centred at $52^\circ 54' 7'' \text{ N}$, $159^\circ 01' \text{ E}$ at the head of the “Northern” canyon of the Avacha Bay, with a radius of 2 km and comprising 1000 particles.

3. Results

Six numerical experiments were conducted to simulate ichthyoplankton transport: 1) using background surface currents, 2) using background circulation averaged over the upper 200 m layer, and 3) using total circulation in the upper 200 m layer including tidal currents for 2024, with equivalent simulations performed for

² <https://ichthyop.org/>

2025 (experiments 4–6). Passive tracers representing eggs and larvae were initialized as a patch at the head of the “Northern” canyon of the Avacha Bay after ascent into the near-surface layers driven by natural buoyancy and external factors. Horizontal particle displacement was tracked from 4 April 2024 (spawning peak) to 3 May 2024 and over the same period in 2025. Two additional simulations examined particle drift under tidal currents alone for the selected periods in 2024 and 2025.

Figure 5 shows the evolution of tracers at weekly intervals for the total circulation in the 0–200 m layer including tidal currents. The combined panels show that in 2024, particles did not remain over the canyons of the Avacha Bay but were rapidly transported across the wide shelf of the southeastern coast within the first two weeks, with a portion (approximately one-quarter of the initial number) advected into the open ocean. During

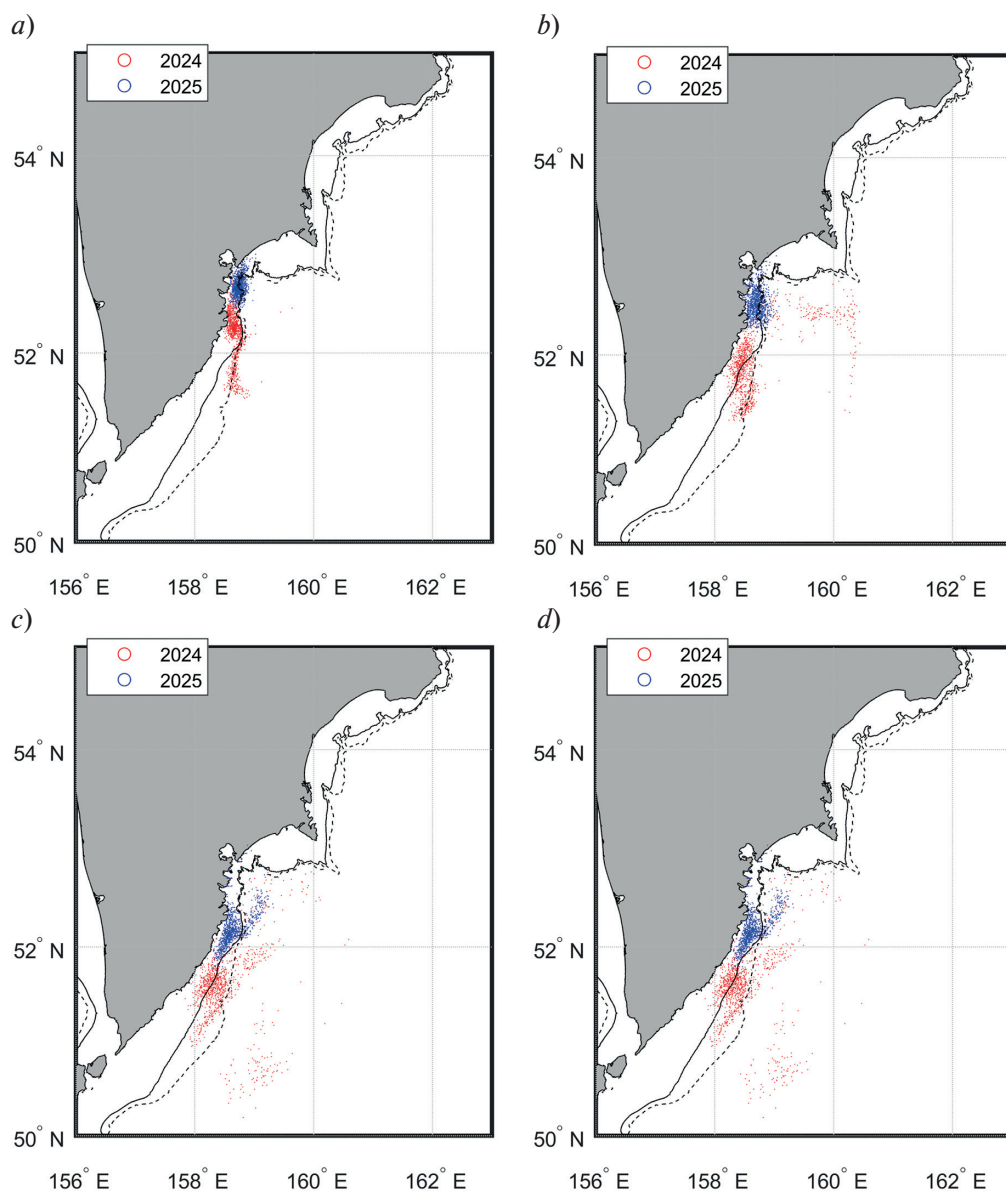


Fig. 5. Position of modelled particles after 7 days (a), 14 days (b), 21 days (c), and 28 days (d) from the start of the simulation, for total velocities including background currents averaged over the 0–200 m layer and tidal currents. Tracers for 2024 and 2025 are shown in different colors. Depth contours of 200 m (solid line) and 500 m (dashed line) are indicated

the subsequent two weeks (Figs. 5b, c), spread over the shelf and were entrained into a large anticyclonic vortex. Some tracers entered the deep-water regions of the open ocean, but most were transported southward along the rest branch of the KKC over the continental slope. Accumulation along the southern boundary of the domain between 157° E and 158° E (Fig. 5d) reflects algorithmic limitations in the implementation of boundary conditions in ICHTHYOP. By the end of the simulation period, only a small fraction of tracers remained in the coastal zone (Fig. 5d).

In contrast to 2024, particle behaviour in 2025 was markedly different, particularly during the first half of the month. Owing to weak background currents, particles remained over the shallow areas of the Avacha Bay and the upper reaches of the canyons, while the particle patch expanded through dispersion (Fig. 5a). The patch gradually migrated southward along the coast (Fig. 5b) and reached the broader shelf only by the end of the third week (Fig. 5c), with most tracers remaining in the coastal zone. Dispersion continued, and by the end of the simulation the majority of particles still occupied the shelf and continental slope as a compact “cloud” (Fig. 5d). Corresponding animated sequences are provided in the Supplementary Materials³.

The influence of different types of circulation on particle transport in ICHTHYOP is considered further. Figure 6 shows simulation results at the end of the monthly interval for scenarios with and without specific factors. It is evident that the choice of velocity fields affects not only the distance travelled from the initial release point but also the pattern of dispersion. Particles spread furthest when only surface currents were used (Fig. 6a); in 2024, tracers dispersed widely over the shelf and into the open ocean, whereas in 2025 they largely remained compact. Note that tidal currents were not included in these simulations.

Simulations using circulation averaged over the upper 200 m (excluding tides) are shown in Fig. 6b. The final distribution for 2024 in this scenario (Fig. 6b) resembles that obtained with total circulation for 2024 (Figs. 5d and 6d), indicating a comparatively minor contribution of surface currents in this case. By contrast, in 2025 (Fig. 6b), nearly all tracers remained over the shallow areas of the Avacha Bay where the average (in the upper layer) currents are very weak.

Figure 6c, representing a simulation driven solely by tidal currents, clarifies this pattern. Tidal currents continuously disperse the initial particle patch over a wide area, primarily due to the oscillatory velocity field combined with nonlinear residual tidal transport (see Section 2.2). This process facilitates the transport of particles to deeper parts of the shelf and the continental slope, where velocities averaged over the upper 200 m are sufficient to advect them away from the release site. This is illustrated in Fig. 6d, which corresponds to the total circulation scenario already described in Fig. 5d.

Simulation results for tracers clearly depend on the prevailing circulation system in the region, including the accuracy of reanalysis or forecast fields for background circulation. However, a realistic description of drift also requires consideration of the tidal component of water dynamics. Unfortunately, verification of tracer simulations is not feasible due to the lack of reliable field data on the spatial distribution and dynamics of pollock eggs and larvae. Nevertheless, it is important to highlight factors that are likely to influence the results and introduce additional differences between simulated particle distributions and observations.

As noted above, the accuracy of background current estimates — particularly in the coastal zone — undoubtedly affects model outcomes. Additional sources of uncertainty arise from parameterizations in ICHTHYOP of egg and larval development processes, such as mortality due to adverse environmental conditions, which alters the total number of particles, or larval behaviour at later stages, including vertical feeding migrations, as well as more complex particle–shore interactions and other factors. Another important consideration is that the actual number of spawning sites exceeds that used in the simulations, with interannual variations in spawning intensity and timing. Moreover, ICHTHYOP can incorporate other dynamic processes, such as wind- and wave-driven drift. Accounting for these factors requires additional input data and greatly increases the number of possible model scenarios. These processes were omitted here, as the objective was to assess the influence of water circulation on egg and larval transport under identical spawning conditions.

³ Mercator-Fesom-200m_ichthyop_Apr2024. URL: <https://rutube.ru/video/95287b1f7a5d1e26244b446defbcece6/> (date of access: 23.11.2025); Mercator-Fesom-200m_ichthyop_Apr2025. URL: <https://rutube.ru/video/4d0d5eadb53a22c9d7f1987f169f76f/> (date of access: 23.11.2025)

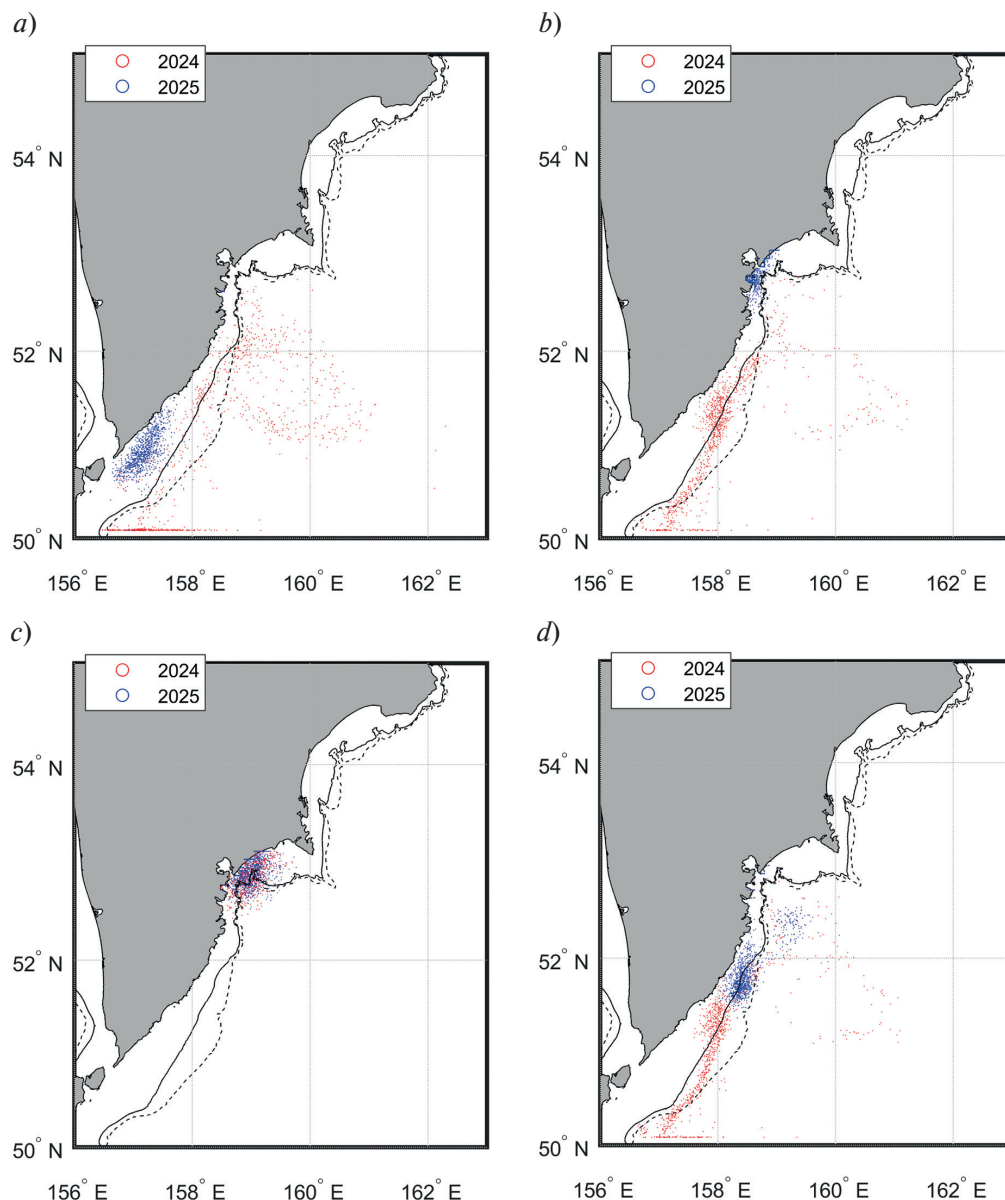


Fig. 6. Particle positions at the end of the simulation interval obtained using surface currents (a), currents averaged over the 0–200 m layer (b), tidal currents (c), and total currents (tidal plus 0–200 m averaged) (d). Tracers for 2024 and 2025 are shown in different colors. Depth contours of 200 m (solid line) and 500 m (dashed line) are indicated (panel d is the same as panel d in Fig. 5)

4. Conclusion

Using the prepared datasets for 2024 and 2025, simulations were conducted to model the transport of passive particles representing pollock eggs and larvae from the deep-water spawning site at the head of the “Northern” canyon of the Avacha Bay. According to recent data, this site constitutes the principal center of reproduction for the East Kamchatka population of pollock. The canyon is considered to provide dynamically favourable conditions for egg development during April–May. As development proceeds, eggs ascend and enter the near-surface layer, where currents can advect them and the newly hatched larvae into regions with varying thermohaline and feeding conditions. Vertical particle displacement may also be influenced by external factors, such as internal tides observed at the head of the canyon.

Particle drift over the simulation period strongly depends on the circulation established during the spawning season. Model results indicate that, compared with 2024, particles in 2025 moved more slowly and remained closer to the coast, in warmer and potentially more food-rich waters, enhancing the chances of ichthyoplankton survival and subsequent juvenile development. In 2024, a substantial fraction of particles dispersed across the domain or drifted into the open ocean, where conditions for egg and larval survival are less favourable.

The use of currents averaged over the upper layer, rather than surface currents alone, is justified in this study, as not all eggs or larvae ascend to the near-surface layer. Simulations using surface circulation data show that particles reaching the surface are rapidly advected from areas of weak hydrodynamics and dispersed more widely across the domain. Observations indicate that pollock larvae in the Avacha Bay develop below the photic layer [27], further supporting the use of currents averaged over the upper layer.

Using the 2025 dataset as an example, it is shown that the addition of tidal currents to background circulation promotes local dispersion of particles and can impart an additional momentum to their movement, preventing their accumulation in a confined area. The significance of this effect for the survival of pollock eggs and larvae remains unclear and warrants further investigation, including dedicated ichthyoplankton surveys.

Two preliminary conclusions can be drawn from the results. First, based on the simulations, 2025 appears to have provided more favourable dynamic conditions for the survival and development of early pollock life stages than 2024; the extent to which this “forecast” will be realised remains to be seen. Second, the results provide guidance on where particle accumulation can be expected as a consequence of advection by the circulation system. As indicated in Fig. 5c, this corresponds to a coastal region with a characteristic widening of the shelf near 158.5° E, 52.25° N, where both background and tidal currents weaken.

It is evident that the next phase of research will involve the acquisition of new ichthyoplankton data and the development of a regional three-dimensional model that accounts for the full range of dynamic processes and the specific hydrology of region.

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Conflict of interests

The authors declare no conflict of interests.

Supplementary Materials

Simulation results corresponding to Fig. 6 are presented as animations from the ICHTHYOP interface for 2024: Mercator-Fesom-200m_ichthyop_Apr2024 (<https://rutube.ru/video/95287b1f7a5d1e26244b-446defbcece6/>) и 2025: Mercator-Fesom-200m_ichthyop_Apr2025 (<https://rutube.ru/video/4d0d5ead-b53a22c9d7ff1987f169f76f/>).

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