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Daily and Seasonal Variation in Downstream Migration of Juvenile Pink Salmon *Oncorhynchus gorbuscha* (Salmonidae) in Rivers across the Sakhalin and Kuril Region

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Abstract—The four-year study outcomes for downstream migration of the juvenile Pink salmon *Oncorhynchus gorbuscha* in the Bolshaya Khuzi, Malaya Khuzi, Lazovaya, and Voznesenka Rivers on the East Sakhalin Island and in the Rybatskaya River on the Iturup Island, located far apart from one another along a meridian line (between 45° and 51° N) in different climatic regions, are present. Almost all smolts could migrate over two months, May and June. Similar trends in dynamics of daily downstream smalt migration in all the rivers, associated with reduction in the period of mass migration recorded at dark time during each 24-hour day at approaching the date of the summer solstice, were recorded. The climate patterns of regional variations (dates and degrees of warming trends, heavy precipitation at southern latitudes) significantly modify the pattern variations in the downstream migrant number (downstream migratory phases of increased and decreased passage activities) over a season relative to the river temperature and flow regimes under the spring warming conditions. Therefore, the relationships between the smolt downstream movement rate and the river water temperature and level tend to become weaker, largely, in the southern regions under the impact of the short-term weather variations in unsettled patterns relative to the impact strength and duration.

Keywords: juvenile Pink salmon, downstream migration, local time in 24-hour format, water level and temperature, Full Moon, Sakhalin Island, Iturup Island

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INTRODUCTION

Juvenile fish downstream migration (descending) is the essential life-cycle element in the anadromous fish, oriented on spatial distribution to seek feeding areas. The fate of fish generations can therefore depend on this migratory success factor affecting the fish population sizes and the migratory patterns and scales in the subsequent life cycle stages of fish (Pavlov, 1994). Hence, multiple research papers are focused on the downstream migraton, indicating the high variability in its analyzed patterns and trends relative to the regional geography, river-valley geomorphology, meteorological conditions, etc. With respect to the Cakhalin and Kuril region, it is of great importance, because of a considerable north-south distance and different thermal regimes of the seawaters surrounding the region, which causes the variations in climatic conditions between the certain areas (*Atlas*..., 1967). In this context, a comparison of downstream migration patterns for different rivers is rather vital. Such generalization of downstream migration dynamics in the juvenile Pink salmon *Oncorhynchus gorbuscha* and environmental conditions was performed for the rivers flowing across the northern part of the East Sakhalin Island in certain years between 1960–1970 (Gritsenko et al., 1987). In addition, its updated version for the Esat Sakhalin Island included the survey-based results for the Bakhura River (the southern part of the Island), produced in 1980s (Gritsenko, 2002). The data obtained in the last years allow us to compare the downstream migration patterns for the juvenile fish of this species in the rivers flowing across the regions (between 45° snd 51° N) different in climatic conditions between the northern and southern parts of the East Sakhalin Island and the Iturup Island. The high reproductive efficiency of the Pink salmon in these areas, providing ~80% of the total catch of this fish species in the region, tends to add the special importance for this comparison. The objective of this research survey is to identify both the characteristic patterns of the juvenile Pink salmon downstream migration in the rivers across the major districts of its production within the Cakhalin and Kuril region and the possible reasons causing these patterns.

Table 1. Downstream migration timing of the juvenile Pink salmon *Oncorhynchus gorbuscha* in the rivers across the Sakhalin and Kuril region in records of the dates using the day—month—year format

River	Year	Period of records (day, month)	
		start date	end date
Bolshaya Khuzi	2019	19.05	06.07
Malaya Khuzi	2021	16.05	15.07
	2022	01.06	09.07
Lazovaya	2019	16.05	25.06
	2020	20.05	24.06
	2021	23.05	19.06
	2022	18.05	24.06
Voznesenka	2014	14.05	15.06
	2015	18.05	24.06
	2019	13.05	13.06
	2020	14.05	10.06
Rybatskaya	2019	06.05	24.06
	2020	08.05	21.06
	2021	01.05	20.06
	2022	29.04	21.06

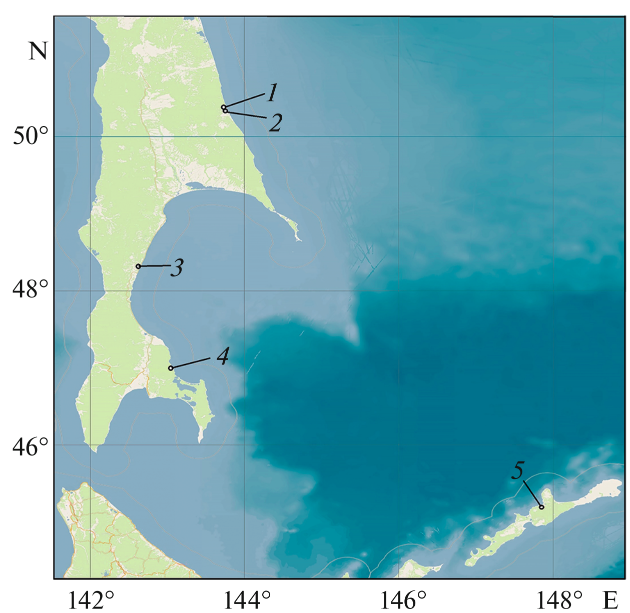

Fig. 1. Schematic map showing locations for recording the juvenile Pink salmon *Oncorhynchus gorbuscha* descended the rivers flowing across the Est Sakhalin Island coast (*1*–*4*) and the Iturup Island (*5*): (*1*) Bolshaya Khuzi River, (*2*) Malaya Khuzi River, (*3*) Lazovaya River, (*4*) Voznesenka River, and (*5*) Rybatskaya River.

MATERIALS AND METHODS

The primary data from the quantitative records of the juvenile Pink salmon in downstream migration were used. The data were produced during the survey operations in the Bolshaya Khuzi and Malaya Khuzi Rivers, the Lazovaya River, and the Voznesenka River flowing across the eastern coast of the Sakhalin Island and the Rybatskaya River on the Iturup Island by the researchers, All-Russia Research Institute of Fishery and Oceanography, Sakhalin Branch (SakhNIRO) (Table 1, Fig. 1). Considering the river-fish habitat inventories including the generative lineages reproductively isolated in the odd- and even-year stocks of the Pink salmon, two generations of each leanage were analyzed for each river, excluding the rivers across the Northeast Sakhalin coast because of insufficient data available, since their collecting was lately renewed after a break in time series over multiple years. All the comparatively small rivers chosen for recording have the characteristics of the mountain streams typical for Pink salmon spawning, based on the abundance estimates of the spawning stocks on the spawning grounds, when compared that with the large rivers flowing through the vast valleys (Kaev et al., 2010).

The catch records was performed with the fish sampling method adapted for use in small watercourses on the Sakhalin and Kuril Islands (Volovik, 1967; Kaev, 2010). The smolt-monitoring sluice gate locations were identified by meeting two criteira: the location of the Pink salmon fish spawning ground in the upper reaches of the river and the distance from the river mouth outside the zone of influence of tides. A conical trap with a square inlet 50 × 50 in size served as a fishing tool was set every hour from dusk till dawn in fishing control position (in the midstream, as a rule). The catches in 24-hour sessions were not performed, since the Pink salmon downstream migration in small mountain rivers within the boreal zone was primarily nocturnal. The datasets for the Malaya Khuzi River (Kirillov et al., 2018) show that if the Pink salmon migration is recorded to be diurnal at river flooding, its activity is considered insignificant, when compared to the nocturnal passages in assessing the overal migration success. Any juvenile Pink salmon fish were not recorded during the casual catching trips in the Rybatskaya and Chistaya Rivers and the small stream channels of Lakes Sopochnoe and Kuibyshevskoe on the Iturup Island at dusk in June 1984.

In order to estimate the number of smolts descended the river, ranges of special catches were periodically made setting successively the conical trapping in different positions across the river from one bank to another. It could allow us to determine the number of smolts cought with the trap in the control position as a portion of the total smolt run across the face of a sluice gate on the river at given time (Kaev, 2010). The start dates for recording were determined relative to the results in catching the smolts in previous years. The records were usually ended, if the total catch in terms of the number of fish was no more than two–three downstream migrants caught in each fishing period at night. Considering these nuances, the profiles for dynamics of smolt downstream migration were designed in proportions to its variations recorded for the nearest nights, based on the survey records for the other river within the given area. The annual value deviated, on average, by 2.67% at the highest values over each season, which comprised 0.07 to 1.69% of the total number of the smolts descended the river. The larger percent error values (untill a double increase in the smolt number) are commonly known, repeatedly calculated based on the expert estimates with the use of the previously reported data on the dates and the dynamics of downstream migration in the study river and the other rivers flowing across the given area, meteorological conditions, etc. These experts' reports are regarded as probably helpful for the survival estimates for the Pink salmon new generations and the retrospective assessment of the spawning stock expected to return (Pavlov et al., 2015; Kirillov et al., 2018).

Seasonal downstream migration duration was estimated by the dates of the event over the period, when 99% downstream migratory fish desended the river. It allowed us to reduce the uncertainty of values calculated at scarce catches of smolts. If the given range involved the recovered data on the nocturnal downstream passage, exceeding the limit submitted to it in the experience gained (1.7%), the results of such records were not analyzed because of significant lack of information on the downstream passage dynamics especially on its rise. For this reason, the project to study the downstream migration in different rivers within the same range of years failed (Table 1).

The monitoring system included the water level and temperature records. The water level relative to the arbitrary zero level was measured at the evening hours, if no visible parameter changes were observed during the night. The water temperature was measured during common fishing periods of catching with each trap installed. Since the water rather rapidly cooled, the average water temperatures were estimated for a period of in-night measuring relative to reduction in duration of darkness. The light performance was assessed visually at dusk, dawn, and night with respect to the moon occurrence and weather conditions. Such estimates are quite objective, since the night light level intensity measured with tools can approve its change relative to the Moon phases and positions in the sky, the moonrise and moonset time, and meteorological conditions including the phenomena such as cloudiness and fog (Kirillov et al., 2018).

Catch series at dark time were performed under the every-other-night shedule. The numbers of smolts descended the river and the water temperatures and levels for the missing nights were regarded as the averages of the two adjacent values. Various authors in their publications tend to assess the interdependent parameter variables by a degree of diagram fragment coincidence and through pair-correlations between them, finding the conjugacy ratio of the downstream movement rate to the water temperature and level. The two-way analysis of variance cannot deal with this case, since sychronous variables for the water level and temperature are multidirectional more frequently. Therefore, the Pearson's pair-correlation (r) method was traditinally used to reveal the relationships, while the estimates were performed with two variants for more careful analysis. The measured values were expressed as percentage of their averages for each year, which could allow us to produce the uniform data set for each year of observations. In the first variant, the pair correlation coefficients are estimated separately with the measured values for the period of mass downstream migration of ~60% smolts and, consequently, the start and end periods. In the second variant, the pair correlations between the synchronous parameter-value deviations of their previous values were estimated to increase the number of downstream migrants (from the initial catches until the date for recording a half of smolts descended the river).

The information on the weather state in any locality was assessed by the daily data provided by hydrometeorological stations (HMS) to display on the rp5 Weather Shedule website (http://rp5.ru). Hydrometeorological observation records for the Malaya and Bolshaya Khuzi Rivers were available from the HMS station in Pogranichnoe Village (HMS 32076, 50°24′ N, 143°46′ E). The records for the Lazovaya, Voznesenka, and Rybatskaya Rivers were available from the HMSs in Makarov Town (HMS 32116, 48°38′ N, 142°46′ E), Dolinsk Town (HMS 32133, 47°20′ N, 142°48′ E), and Kitovoe Village (HMS 32174, 45°15′ N, 147°53′ E), respectively. The obtained data were processed with the Microsoft Excel.

RESULTS

The character of the *Bolshaya Khuzi River* (29 km in length) and the *Malaya Khuzi River* (32 km in length), flowing from the spurs of the East Sakhalin Mountains, is determined by the positions of the mountains. The distance between their mouths is ~1.5. The salmon spawning ground areas comprise 27.5 and 37.0 thousand m^2 in the first and second rivers indicated above, respectively. The Pink salmon fish generally spawn in both rivers. In 2019, the SakhNIRO researchers recorded the juvenile salmon fish in the Bolshaya Khuzi River. The obtained record outcomes were found similar to the records performed for the Malaya Khuzi River in the same year by the researchers at the Severtsov Institute for Problems of Ecology and Evolution, Russian Academy of Sciences. Thus, 90% smolts descended the Bolshaya Khuzi River from May 25 to June 29, while the smolts

Table 2. Average portions of the downstream migrating juvenile Pink salmon *Oncorhynchus gorbuscha* per 1h of downstream migration at diferent times in 24-hour day format relative to phases of increase (A) and decrease (B) in the numbers of juvenile fish descende the different rivers (average data for years of observations), %

Time, h	"Khuzi"*		Lazovaya		Voznesenka		Rybatskaya	
	A	B	A	B	A	B	A	B
20	0	0	0	0	0	0	0.59	0
21	0.27	0	0.78	0.51	0.14	0.10	10.78	1.01
22	1.90	0.47	4.46	4.19	2.65	2.35	35.82	25.07
23	9.54	7.76	9.86	11.85	13.81	13.52	24.84	34.92
24	20.52	19.93	12.93	14.97	22.94	20.93	12.71	19.64
01	22.62	21.46	14.11	18.54	22.39	22.35	7.44	11.00
02	22.14	20.17	16.99	20.16	17.33	19.09	4.28	5.09
03	14.30	20.44	18.45	15.79	11.69	13.96	2.12	2.09
04	7.26	8.87	13.53	10.63	7.36	6.80	0.96	0.87
05	1.30	0.90	7.51	3.08	1.60	0.88	0.41	0.28
06	0.15	0	1.32	0.28	0.09	0.02	0.05	0.03
07	0	0	0.06	0	0	0	0	0

* Here and in Table 3: combined data for the Malaya Khusi and Bolshay Khusi Rivers.

descended the Malya Khuzi River (Kirillova, 2019) from May 24 to June 26. In addition, the certain major peaks in these migration waves coincided with one another in timing. Therefore, the data for the Bolshaya Khuzi River were considered to add to the datasets for the Malaya Khuzi River in order to keep the observation there for consecutive years with the SakhNIRO researchers involved in the exploration team symbolically named as Khuzi Group.

Smolts descended the river at the highest rate from 00:00 to 03:00 during each 24-hour day. Thus, 79.6 and 82.0% downstream migrants, on average, migrated downstream within this period in the first half (phase of increasing passage efficiency) and the second half of downstream migration (phase of decreased passage efficiency), respectively (Table 2). In 2019 and 2021, the rates of downstream movement tended to decrease under the Full Moon. In 2022, it tended to increase after a short-term decrease before the Full Moon at the reference occurrence of dense cloudiness (100%). Theoretically, the downstream passage was longest in 2021 (61 nights) due to the greater estimated number of smolts descended the river in the middle of May (Fig. 2). However, these data were produced based on the solitary smolt cathes at the irregular trap operation position because of flooding. Lack of catches or accidental subsequent nocturnal catches of smolts were the reasons for rejection to perform a range of smolt catches in order to adjust solutions accouts for densities of migratory smolt run relative to different positions of a sluice gate on the river. A range of such catches was performed only at night on June 13 at the reference decline of the water level in the river, allowing us to catch the smolts at all the sluice gate positions, while the biggest catches were recorded in the midstream. The survey-based data showed that until May 26, the catching positions were beyond the limits of the main migratory smolt run, which is frought with the serious erros in calculations of downstream migrant numbers (Kaev, 2009). Therefore, the datasets obtained before May 26 were not used in analytical estimating. Considering this nuance, duration of downstream migration over three years comprised, on average, 42 (33–47) nights. However, 90% downstream migrants passed, on average, over 29 (21–36) nights.

The downstream migration occurred at the reference decline in the volume of water flowing because of snow gradually melted. This process was generally associated with the spring warming trend. The water level declining at more rapid rates within the smolt migration descending the river was probably caused by abundant precipitation in May (179 mm), melting the lying snow, and rather low precipitation in June (22 mm). In 2019 (103 mm in May and 46 mm in June) and 2021 (151 and 68 mm, respectively), the month-to-month differences were not so considerable.

In the early period of downstream migration, a positive correlation between the downstream movement rate and the water temperature and a negative correlation with the water level were found. In the late period, the contrast pattern was obseved. The negative correlation of the movement rates with the water temperature and a positive correlation with the water level were revealed. During mass downstream migration, the coefficient values for correlations of downstream movement with water temperature and its level were lower. A relationship between the downstream move-

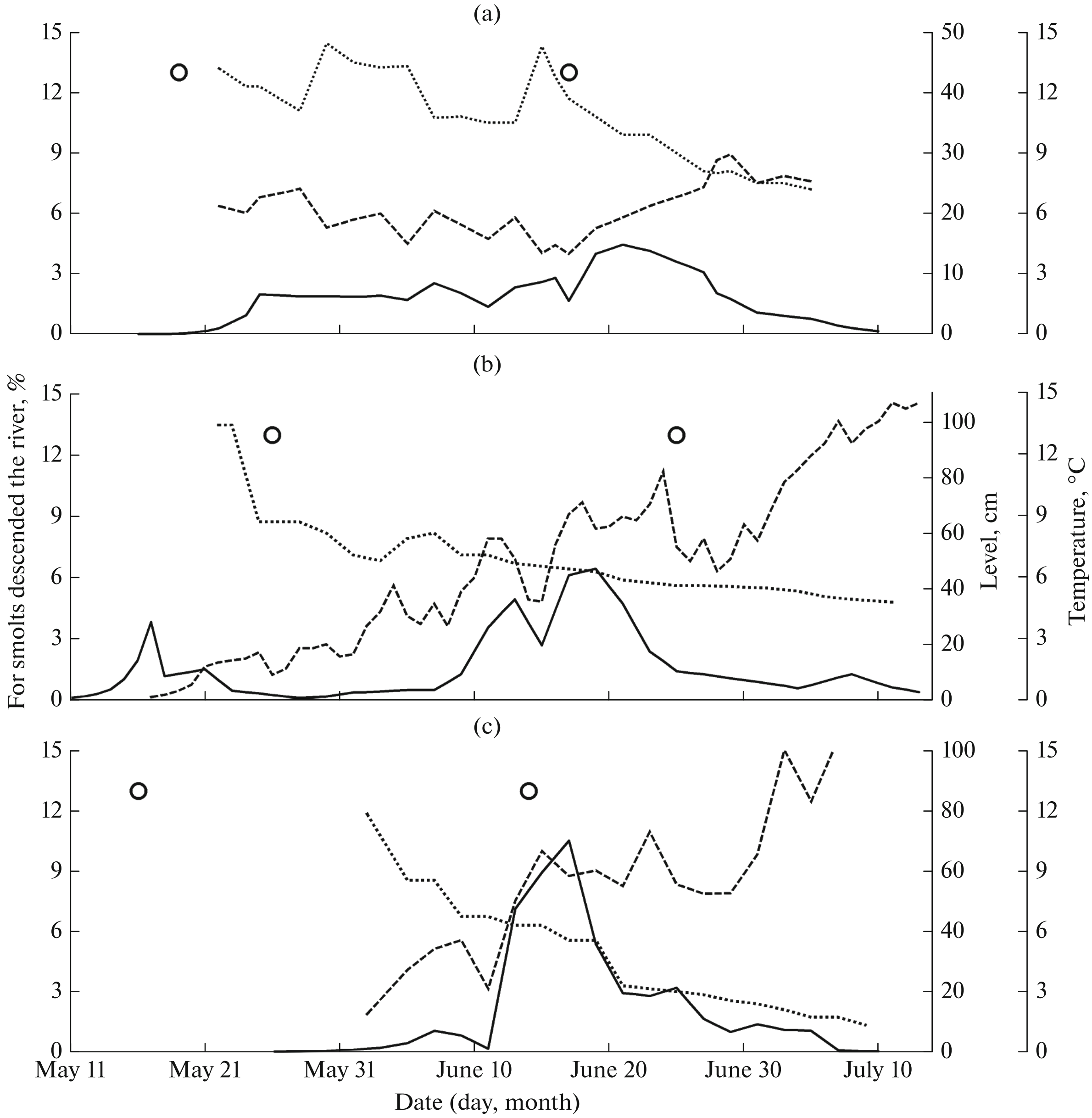

Fig. 2. Dynamics of downstream migration in smolts of the Pink salmon *Oncorhynchus gorbuscha* (—), water temperature (– – –) and level (·····) in May–July for the Bolshaya Khuzi River in 2019 (a) and the Malya Khuzi River in 2021 (b) and 2022 (c): (○)—full Moon dates.

ment rate, calculated with deviations of each parameter measured in the phase of increased number of downstream migrants, and the water temperature was found weaker than the model estimated with their actual values for the early migration period, while the relationship with the water level almost failed (Table 3). The earliest smolt mass downstream migration occurred in 2019. Its start coinsided with the warm up the spring in that year, when the average air temperature in May comprised 3.9°C contrary to 2.0 and 2.6°C in 2021 and 2022, respectively.

The Lazovaya River (36 km in length, 220 thousand-m^2 spawning ground area predominantly for the Pink salmon fish) has mainly a character of a mountain river generally flowing across the southeast spurs of the Kamyshovy mountain ridge. In the phase of increased passage activities, the main portion of the juvenile fish (86.8%) migrated during different nights from 24:00 to 04:00 h in 24-hour time format. In the phase of decreasing the passge activities, a change in timing of downstream migration of most juvenile fish (81.3%) occurred, shifting to the earlier period from

Table 3. Coefficients of correlation between the variables for smolt numbers in the Pink salmon *Oncorhynchus gorbuscha* and the water temperatures (*t*) and levels (*h*) in different periods of downstream migration (measurement data) and phases of increased smolt numbers (deviations from values), based on the averages over the years of observations for different rivers

River	Parameter	Downstream migration periods			Phase of increase
		early	middle	end	
"Khuzi"*	*t*	0.78	0.40	−0.44	0.70
	h	−0.37	0.34	0.60	0.03
Lazovaya	*t*	0.10	0.31	0.31	0.08
	h	0.30	0.02	−0.03	0.01
Voznesenka	*t*	0.76	0.49	0.18	0.48
	h	−0.32	−0.19	−0.13	−0.13
Rybatskaya	*t*	0.30	0.00	−0.11	0.22
	h	−0.26	0.04	0.25	0.18

23:00 to 03:00 h in the 24-h format (Table 2). The duration of downstream migration comprised, on average, 39 (35–45) nights. However, 90% downstream migrants passed, on average, over 26 (23–33) nights. The earliest start date for the smolt downstream megration was recorede in 2019. Thus, 56% smolts migrated in May contrary to 23–35% smolts passed in the following years. The average air temperature in the first and second halves of May 2019 comprised 5.2 and 10.1°C, respectively. In June, it remained at the same level (comprising, on average, 9.0 and 10.1°C for the first and second halves of June, respectively). Year 2022 in contrast to 2019 was characterized by the average daily air temperatures higher than 10°C, recorded only in the second half of June. With respect to 2020 and 2021, the air temperatures were recorded at the intermediate levels. The water temperature regime in the river quite enough corresponded to the air warming trend patterns, considering the fact that by the second half of May in 2019, warming the river water reached the level tending to remain the same during June (Table 3). Variations in the water level were generally associated with melting the rest snow cover at higher rates on warm days (until 20°C at the end of May 2020) or under heavy presipitation in combination with warm weather (flooding occurred in early June 2021, 44 mm precipitation over two 24-h days). Despite considerable variations in the water temperature and level regimes in the river, any significant relationships between the rates of downstream movement and these parameters were not revealed based on both the comparisons of the values observed for different periods of downstream migration and the appropriate deviations within a phase of increased passage activities of smolts (Table 3). The peaks of downstream migration activities were recorded between the full Moon phases. Only in 2020, the peak of downstream migration activity tended to occur shortly before the Full Moon in early June. However, the peak was not reached because of decreasing the number of downstream migrants under the full Moon effect.

The Voznesenka River (14 km in length, 21 thousand-m^2 spawning ground area generally of the Pink salmon) is mostly a mountain river flowing from the Susunaisky mountain ridge. The juvenile fish descended the river at the highest rates from 23:00 to 03:00 in 24-hour time format. The proportions of downstream migrants in downstream migratory phases of increased (88.2%) and decreased (89.8%) passage activities were found rather similar. However, certain shifting towards later timing of downstream migration occurred in that case. It is evidently proven by both a comparison of the peak values for the phases of increased and decreased passage activities (at 24:00 and 01:00 in 24-hour time format, respectively) and bigger smolt catches observed in the phase of decreased activities at 02:00 and 03:00 in 24-hour time format (Table 2). Duration of downstream migration over the study years comprised, on average, 31 (24–38) nights. In addition, the major portion of juvenile fish (90%) tended to descend the river in the shorter term, over 19 (16–24) nights. The fish longer lifespan in 2015 was caused by shifts in timing of the main mass downstream migration to the later start dates and consequently the later end dates (Table 4). The earliest and shortest period of mass downstream migration was observed in 2019, when the water temperature in the second half of May was higher than that in the first half of June, in contrast to the conditons in the other study years. Rises in the river levels within the records surveys were associated with heavy rains, most intense in June 12–19, 2014 (131 mm), while it could not cause a simultaneous decrease in the water temperature, frequently observed with rapid thaw of snow. In the initial period of downstream migration, the strongest positive correlation between the smolt passage and the water temperature was revealed, while a weak negative correlation between the smolt passage and the water level was found. In the period of mass downstream migration and at the end of the migration period, the correlation coefficent values tended to decrease gradually, indicating that the positive or negative direction of the study associations between variables remained unchanged. The analysis of synhronous time deviations of the study parameter values in the phase of increased passage activities showed that the directions of associations between variables remained unchanged. However, their strength evidently decreased, when compared that in the initial downstream migration period (Table 3). In 2014, almost all juvenile fish could descend the river in the period between the full Moon phases, with a migration activity peak well expressed. In 2015, the trend to increasing the smolt long-term downstream migration at low rates started in the period of the last third of May, which could reach its peak only in the middle of June after the full Moon phase. The downstream migration in 2019 reached its peak under little rainfall events and dense cloud formation shortly after the full Moon phase due to increasing the number of smolts descending the river at high rates. On the contrary, the downstream migration in 2020 reached its peak before the Full Moon, while a sharp drop in the smolt number at setting the Full Moon was recorded.

The Rybatskaya River (8 km in length, 12- and 4.2-thousand m^2 spawning ground areas for the Pink salmon and Chum Salmon fishes, respectively) is mostly a mountanious river flowing from the Rubetsky Ridge. Juvenile fish descended the river when it got dark, first, between 21:00 and 24:00 and, then, between 22:00 and 01:00 in 24-hour time format. Thus, 84.1 and 90.6% downstream migrants, on average, passed within the periods indicated above, respectively (Table 2). Duration of downstream megration over 2019–2022 comprised, on average, 48 (42–54) nights, while 90% juvenile fish migrated, on average, over 27 (22–30) nights. The average air temperatures in May and June were rather similar to those in 2019 (comprising 9.8 and 10.2°C, respectively) and 2022 (9.1 and 8.7°C, respectively). In addition, the temperftures were most different for these months in 2020 (6.4 and 11.4°C, respectively) and 2021 (6.4 and 10.1°C, respectively), which probably caused the different hydrological regimes during the smolt downstream migration. The early spring warmth in 2019 and 2020 influenced the trend to decreasing the water level in the river. However, the river level was comparatively steady in 2020 and 2019 (Fig. 5). The coefficients of correlation between the smolt number variables and the river regimes (water temperatures and levels) represented the lack of association in the period of mass downstream migration, while they indicated weak relationships in the migration start and end dates. In addition, a weak relationship between the rates of downstream movement and the given parameters for environments was revealed in the phase of increased passage activity of downstream migrants at comparing the synchronous time deviations of the appropriate parameter vaues (Table 3). If the wave of a substantial number of downstream migrants came on the dates close to the full Moon dates, the shape of a curve dome on the diagram, characterizing the dynamics of downsream migration, was visualized as a scatter plot. Thus, the maximum daily values for a relative number of smolts descended the river over a night were lower (2029, 2021) than the variables recorded on the dates in the time interval between the full Moon phases (2020, 2022).

The datasets produced based on comparing the synchronous time deviations of the current parameter values with their previous estimates for the phase of increased smolt passage activities have not revealed any significant trends indicating the impact of the water temperature and level regimes in the analyzed rivers on the downstream migration dynamics in the juvenile Pink salmon (Fig 6). The analysis exclusion decision concerns the impact of water temperatures in the Khuzi Rivers.

DISCUSSION

The analyzed rivers have the characteristics (of a mountain river) providing the typical habitats for the Pink salmon fish. They flow across the regions where most of the watercauses support the high reproductive performance of this fish species (Kaev et al., 2010). The study outcomes for the downstream migration in these rivers completely correspond to the overal opinion on the downstream migration of the juvenile Pink salmon in small watercources within the boreal zone tends to occur at nighttime of the 24-hour time period (Volovik, 1967; Gritsenko et al., 1987; Gritsenko, 2002; Pavlov et al., 2010; Kirillov et al., 2018). It has been experimentally determined that the starting and ending times of downstream migration of the juvenile Pink salmon during each 24-hour day are regulated by complex innate behavior patterns (Pavlov et al., 2019). Negative photoresponse and positive thigmoresponse behaviors in juvenile fish are the key factors in selection of habitats that provide daytime shelters to exhibit activity to leave them at dusk. In pre-threshold lighting environments (~0.5 lux), the downstream migrants start exhibiting movement activity, which tends to rise sharply at onset of darkness (<0.1 lux), followed by juvenile fish stock entering the river flow. Fish movement vectors in a rheogradient flow towards the higher velocity flows, thereby, attract the major portion of downstream migrants to pass within the midstream. However, the lighting performance in this case can also affect the distribution of smolts moving through the cross-flow sluice gate. The records of multiple juvenile-fish catches along this gate on the Voznesenka River showed that the smolt fish stock tended to aggreagate in the midstream over the light nights rather than the dark moonless nights (Kaev and Ignatiev, 2015).

The trend of downstream migration of the juvenil Pink salmon to the darkest time during each 24-hour day is well observed at comparing the periods of the most active descent over a night between the seasonal downstream migratory phases of increased and decreased passage activities. Splitting the downstream migration into these phases is perfomed on purpose to smooth probable deviations in dynamics of downstream migration with different smolt numbers. The first phase runs long before the date of the summer solstice, while the dates of the second phase get closer to the solstice occurrence, sometimes including this event date. In the second phase, the rates of downstream movement in all the analyzed rivers at dusk and dawn tend to go down (even coming to a full stop). Consequently, the nocturnal migration timing appears to be compressed further down the river, considering the fact that in each analyzed river, the juvenile fish portions tend to increase in the period of the most intense downstream movement within the second phase. These variations may be explained by reducing the night length with approaching the summer solstice date (Gritsenko, 2002). Therefore, these otcomes can completely corresond to the overal opinion on primary importance of the lighting performance for daily dynamics of downstream migration (Pavlov et al., 2019).

Shift timing of mass downstream migration observed during the night quite well corresponds to reduction in length of a dark period during 24-hour day with approaching the summer solstice date (Table 2). Nearly half of juvenile fish descended the river over a night was recorded in the Bolshaya and Malaya Khuzi Rivers at 01:17 and 01:31 in the 24-hour time format within the first and second downstream migratory phases, respectively. In the Lazovaya, Voznesenka, and Rybatskaya Rivers, it was recorded at 01:58 and 01:30, 00:58 and 01:05, and 22:37 and 23:11 in the 24-hour time format, respectively. Therefore, the father south the river location was, the earlier the halfway point along a nocturnal downstream passage route from the river was reached. The halfway point timing, in its turn, tended to shift to a later time randomly in the second seasonal phase of downstream migration in each river. The Lazovaya River represented exclusion, since the halfway point timing of nocturnal downstream migration was recorded for the latest time, while its shift in the second migration phase was observed, on the contrary, at the earlier time. Therefore, these trends are caused by geographic latitudes of river locations (since a night is longer and twilight is shorter toward the south) and the other reasons. For instance, spawning grounds of the Pink salmon are mostly located in the middle stream of small rivers similar to the rivers analyzed in the survey. In the shortest rivers (the Rybatskaya and Voznesenka Rivers), the major spawning grounds are located not far from the smolt-monitoring sluice gates as in the Lazovaya River and the Bolshaya and Malaya Khuzi Rivers, where the period of nocturnal downstram migration is most elongated because of great lenghts of spawning grounds. In addition, spawning grounds in the Lazovaya River locate, on average, in the upper stream due to the greater distance between their major aggregation and the monitoring sluice gate (approximately by 7–8 km), which can explain the dropout dynamics of nocturnal downstream migration of juvenile fish in this river.

With respect to the data on the local deacrease in the number of smolts descended the river under the Full Moon, there is no reasonable ground to consider all the information available. Such events occurred in the surveys were usually associated with comparatively light nights (Kaev and Ardavichus, 1994; Zelenikhina et al., 2015; Kirillov et al., 2018), which was approved with the use of equipment (Kirillov et al., 2018). However, the long-term observations are required to reveal the specificity of event expression. It is important to determine, since the full Moon factor not so evidently affect the Pink salmon smolts generally descending passively the river as it can be observed in the Chum Salmon (*O. keta*), which smolts vary considerably in their number under the lunar phase changes causing special waves moving downstream between the full Moon dates (Kaev and Romasenko, 2002, 2017).

The data on diurnal downstream migration of the juvenile Pink salmon, usually recorded by researchers, seem to cast doubt on the analysis outcomes for downstream migration activity at twilight and nighttime. In this case, the information of such kind for the rivers flowing across the north coast of the Sea of Okhotsk is not taken into consideration (Marchenko, 2023), since it is associated with the geographic components (circumpolar regions). However, downstream migration of the juvenile Pink salmon in the rivers of the boreal zone, observed at daytime, requires paying attention. First, the information on migration of such kind should be divided between the small rivers and big rivers, for instance, like the Amur River. The juvenile Pink salmon fish descending this upper river at nighttime move further downstream to the lower river also throughout the day, simultaneously feeding. Smolts feed on plankton and surface-drifting benthos. Therefore, their bodies gain weight by 28–30% during such migration (Rosly, 2002).With respect to the small rivers, for instance, the Kura River (the Sakhalin Island Aniva coast), the Iska River (the Sakhalin Gulf continental coast), and the Malaya Khuzi River, the food in the stomachs of the juvenile Pink salmon fish is also recorded. (Antonov and Kim Khe Yun, 2011; Kanzeparova et al., 2015; Kirillova, 2019). However, there is no information on increasing the body sizes of these Pink salmon juvenile fish in contrast to the Chum Salmon smolts, which partially start feeding in freshwater (Kaev, 2003). Therefore, the growing young Chum Salmon moving downstream in shoals at daytime, observed by various researchers (Kaev, 1998; Pavlov et al., 2010; Zelenikhina et al., 2015; Khovansky and Podoroxhnyuk, 2021), are a common phenomenon, especially, in the big rivers. Diurnal downstream migration of the juvenile Pink salmon fish (less intense than nocturnal migration is) is described generally for the big rivers, such as the Poronaya and Tym Rivers, flowing across the Sakhalin Island (Gritsenko et al., 1987). However, diurnal downstream migration of the juvenile Pink salmon fish in the Orlovka River, the tributary of the Poronay River, was repeatedly recorded. In all the cases, such downstream migration in this river was recorded under turbid river water flooding conditions (Kaev et al., 2007, 2012, 2014). It should be also noted that the Orlvka tributary (83 km in length) is significantly longer than the rivers examined in the surveys. The river mostly flows through the Poronay vast valley, where the smolt-managing point is located. The information on diurnal downstream megration of the juvenile Pink salmon fish in the Malaya Khuzi River under flooding conditions (Kirillov et al., 2018) was provided above. Approximately the same situation with downstream migration of juvenile fish of this species in daytime was described for the Velikaya Kema River in the North Primorsky krai (Kolpakov and Kolpakov, 2006). The data on rare daytime Pink-salmon smolt catches in the Iska River (the Sakhalin Gulf continental coast) only included no information relating to the river flow and other conditions (Kazenparova et al., 2015). Excluding the last unclear case, it may be reported that diurnal downstream migration of the juvenile Pink salmon fish in small rivers representing the spawning habitats within the boreal zone is a rare event triggered by high turbidity of flowing water.

The researchers usually consider variations in the river water level and temperature to describe downstream migration of the juvenile Pink salmon. The most noteworthy aspect indicates that the impacts of these factors make the Salmon smolt downstream migration more intense at its initial stage, while the river water may suddenly cool further, causing a decrease in the number of smolts descende the river (Volovik, 1967; Gritsenko et al., 1987; Gritsenko, 2002). In addition, coincidence between the downstream migration timing and the increased water levels is regarded as a significant adaptive phenomenon allowing the juvenile Pink salmon fish to migrate to the sea with minimum energy intake (Varnavsky, 1990). Certain researchers prove this aspect relative to the factors indicated above (Kolpakov and Kolpakov, 2006; Kolpakov et al., 2007; Pavlov et al., 2010; Zelenikhina et al., 2015; Kanzeparova et al., 2015; Kirillova, 2022). Some of them prove this apect relative to the water temperature regime only, considering inconsistency in relationships with water levels (Kirillov et al., 2018) or rejecting any steady relationships between the downstream movement rates and the study parameters (Romasenko et al., 2015). In addition, the outcomes of studying downstream migration in the juvenile Pink salmon are considered ambigous, requiring further discussion.

In fact, the observed rivers are located in different climatic regions (*Atlas*..., 1967). The Malaya and Bolshaya Khuzu Rivers and the Lazovaya River flow across the Middle Sakhalin uplands lying in several climatic regions. The climate of one of them (the southern part of the Northeast Sakhalin coast and the East Sakhalin Mountains), where the Malaya and Bolshaya Khuzi Rivers flow, is under the effect of the cold Sakhalin current making this region coldest within the upland area indicated above in the spring-autumn season. With respect to the other region (east slopes of the Kamyshovy Ridge), where the Lazovaya River flows, the temperature regime is significantly warmer. In addition, this region is different in most precipitation and frequent fog events in the summer season. The Voznesenka River is located in the South Sakhalin climatic region, where the Northwest Monsoon effect tends to reduce in winter, while rainfall is abundant in the second half of the summer and in the autumn season, triggering the warm-season vegetation occurrence. The Iturup Island (the Rybatskaya River) lies in the Kuril climatic region with the main specificity to transfer the marine air in the winter and summer seasons. Therefore, there is the warmest winter season and the coldest summer season within the Sakhalin-Kuril region. However, Iturup is the largest island of the southern Kuril Archipelago, where the Soya warm current warming up this climatic region in summer. The water level variations in the Malaya and Bolshaya Khuzi Rivers are mostly dpendent on long-term snow cover melting at the reference cold weather in May and June, when the air temperatures comprised, on average, 2.8 and 6.4°C, respectively over the years of studying the downstream migration patterns. The strongest relationships between the rates of downstream movement and the parameter data were observed due to the mark trends to gradual warming up the water and decreasing its level in these rivers (Fig. 2). Thus, the strong positive and negative correlations with water temperature and its level, respectively, were revealed in the initial period of downstream migration. In its end period, a change in signs of values for these dependencies occurred. With respect to the mass downstream migration, the pattern showed the intermediate values for a correlation coefficient. The situation like this (the phase of increasing the number of downstream migrants, followed by the phase of decreasing their number at the reference water level dropping after spring flood under warming up the river) may be considered classic for the Sakhalin-Kuril region.

The regions in the south tend to be significantly warmer. Therefore, the snow patch melts away earlier. Consequently, the study characteristics of the river water regime are mostly determined by rainfall events. The average air temperatures in the regions of the Lazovaya, Voznesenka, and Rybatskaya Rivers in May and June comprised 6.3 and 9.6°C, 8.1 and 11.4°C, and 7.9 and 10.1°C, respectively. The regions on the

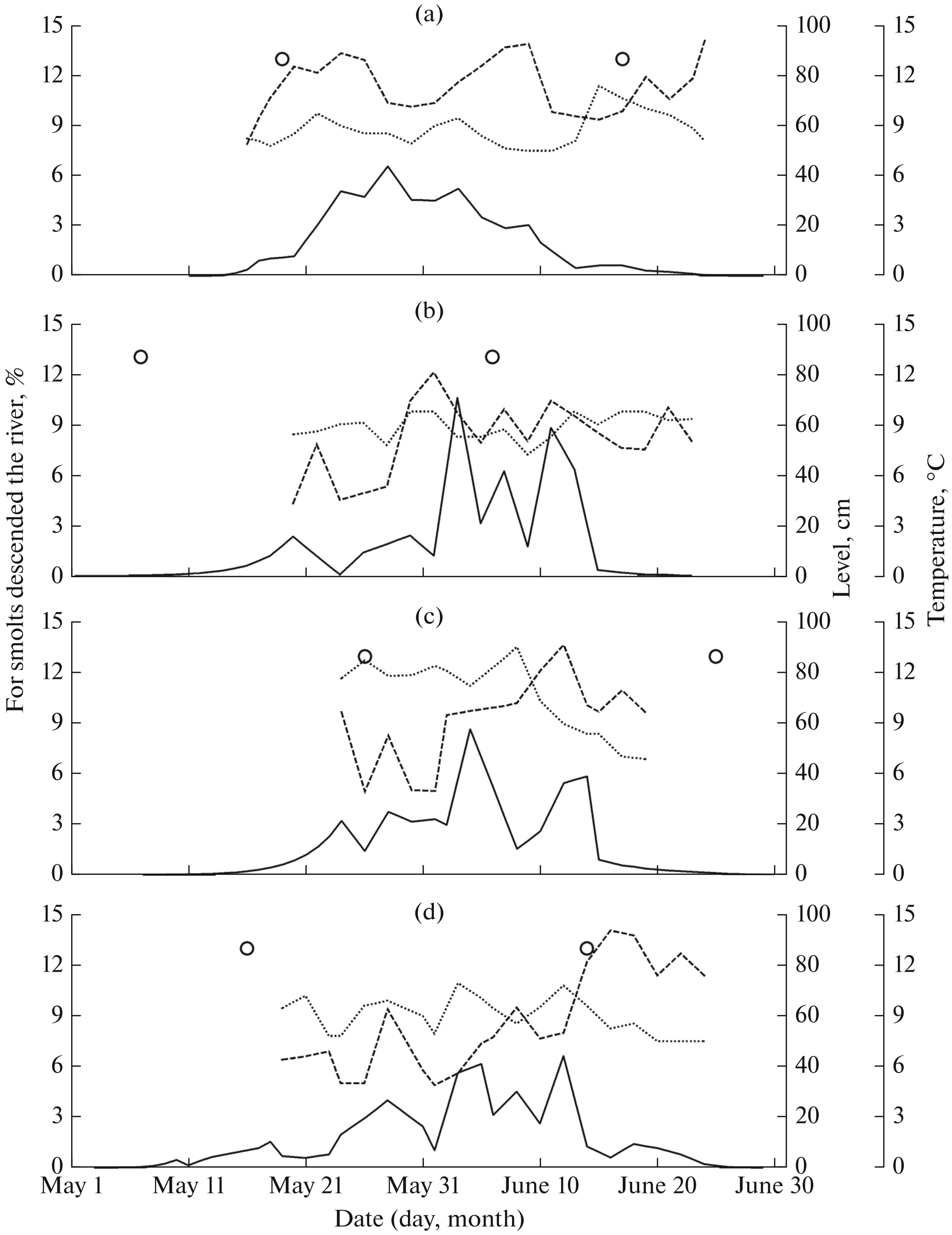

Fig. 3. Dynamics of downstream migration in smolts of the Pink salmon *Oncorhynchus gorbuscha* and water temperatures and levels for the Lazovaya River in May–June 2019 (a), 2021 (b), and 2022 (c). Here and in Tables 4 and 5: see designations for Table 2.

East Sakhalin coast were almost indifferent for precipitation (in the range of 182 to 194 mm) over these months, while it was evidently less on the Iturup Island (135 mm). However, comparing the amounts of precipitation that fell over the periods of records surveys may reveal that the regions that cover sections of the Malaya and Bolshaya Khuzi Rivers (62 mm) and the Voznesenka River (72 mm) are quite different from the river regions of the Lazovaya River (118 mm) and the Rybatskaya River (116 mm). In addition, the strength of correlation between the downstream movement rate and the water temperature in the initial period of the mass downstream migration in the Voznesenka River was approximately similar to that in the Malaya and Bolshaya Khuzi Rivers. With respect to the Lazovaya and Rybatskaya Rivers in the regions with more frequent rainfall events, this relationship was significantly weaker. In addition, a change in the coefficient sign of correlation between the downstream movement rate and the water level to the sign

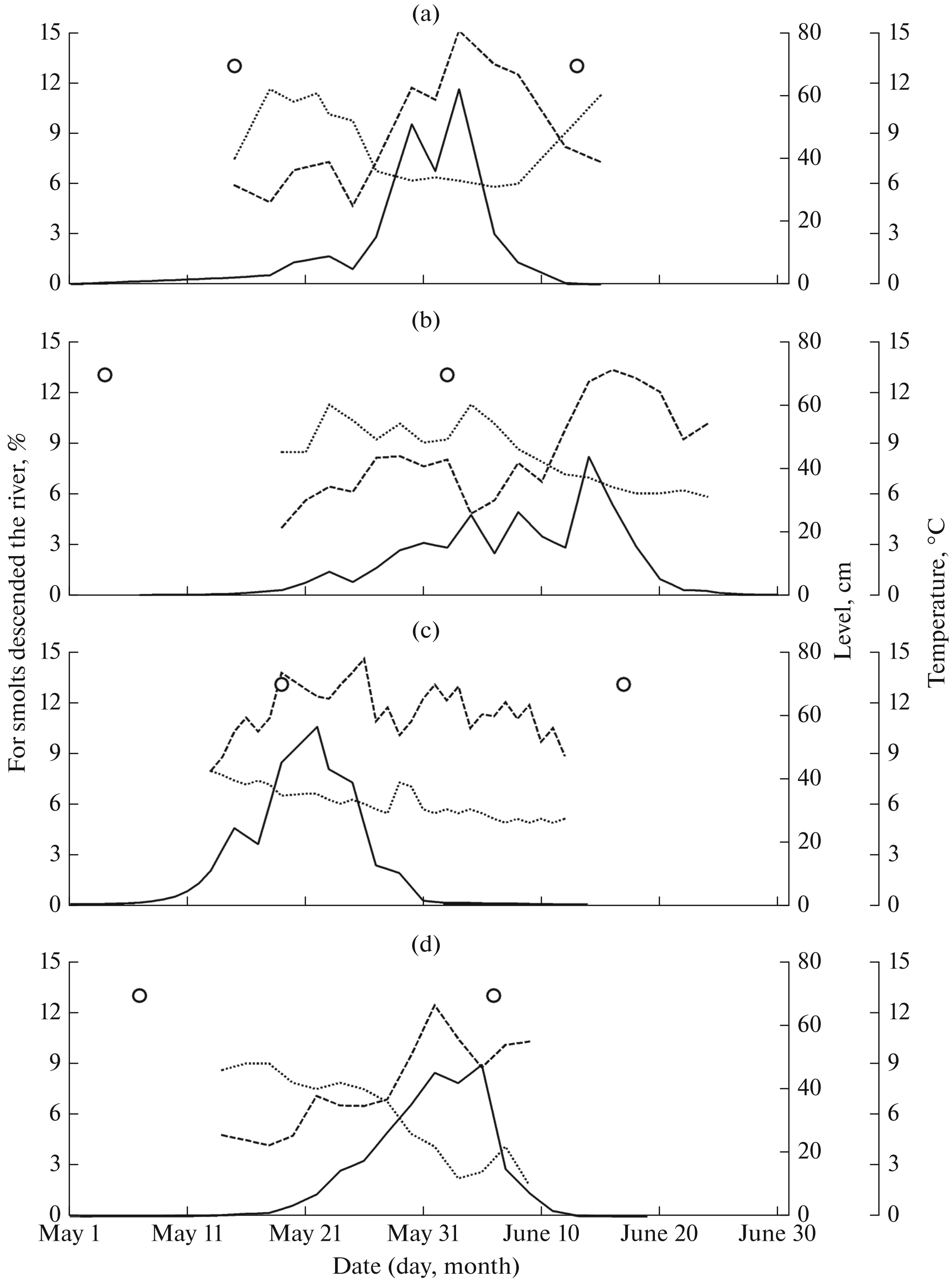

Fig. 4. Dynamics of downstream migration in smolts of the Pink salmon *Oncorhynchus gorbuscha* and water temperatures and levels for the Voznesenka River in May–June 2014 (a), 2015 (b), 2019 (c), and 2020 (d).

opposite to its classical variant, caused by rainfall, was recorded in the initial period of downstream migration in the Lazovaya River and the end period in the Lazovaya and Voznesenika Rivers (Table 3). Classical correlation coefficient matrix, which conveys the associations among the study variables in the initial and end periods of downstream migration, remained unchanged only for the Rybatskaya River, but with decreased appropriate values for the correlation coefficient, when compared to that for the rivers flowing across the Sakhalin Island coast. With respect to all the rivers, it is very essential that the values for a correlation coefficient describing the associations among the downstream movement rates and the water temperatures and levels were calculated based on the synchronous parameter-value deviations in a seasonal phase of

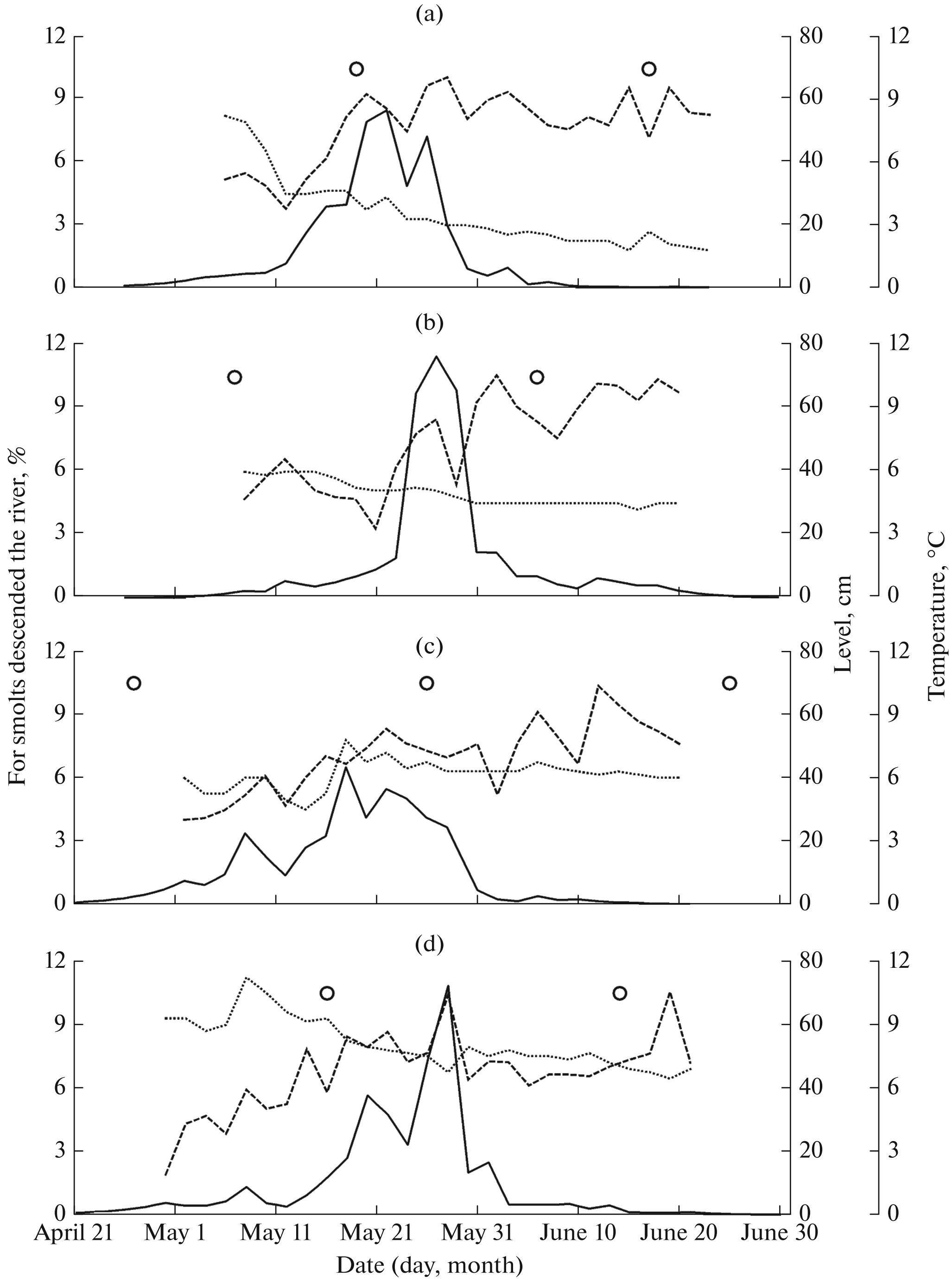

Fig. 5. Dynamics of downstream migration in smolts of the Pink salmon *Oncorhynchus gorbuscha* and water temperatures and levels for the Rybatskaya River in April–June 2019 (a), 2020 (b), 2021 (c), and 2022 (d).

increasing the downstream migrant number. However, they were found lower than the correlation coefficient values calculated based on the variables for the measured estimates of these parameters in the initial period of downstream migration (Table 3). In case of the use of similar timing (a phase of increasing) for both variants, this difference increases to a greater extent in the values for downstream migration—water temperature pairs, since the dataset of the measured estimates is added with the peak values for downstream migration at the reference increasing water temperature.

The divergences in the strength of a relationship between the study pararameters or the low-rank approximation of differnce between these correlation

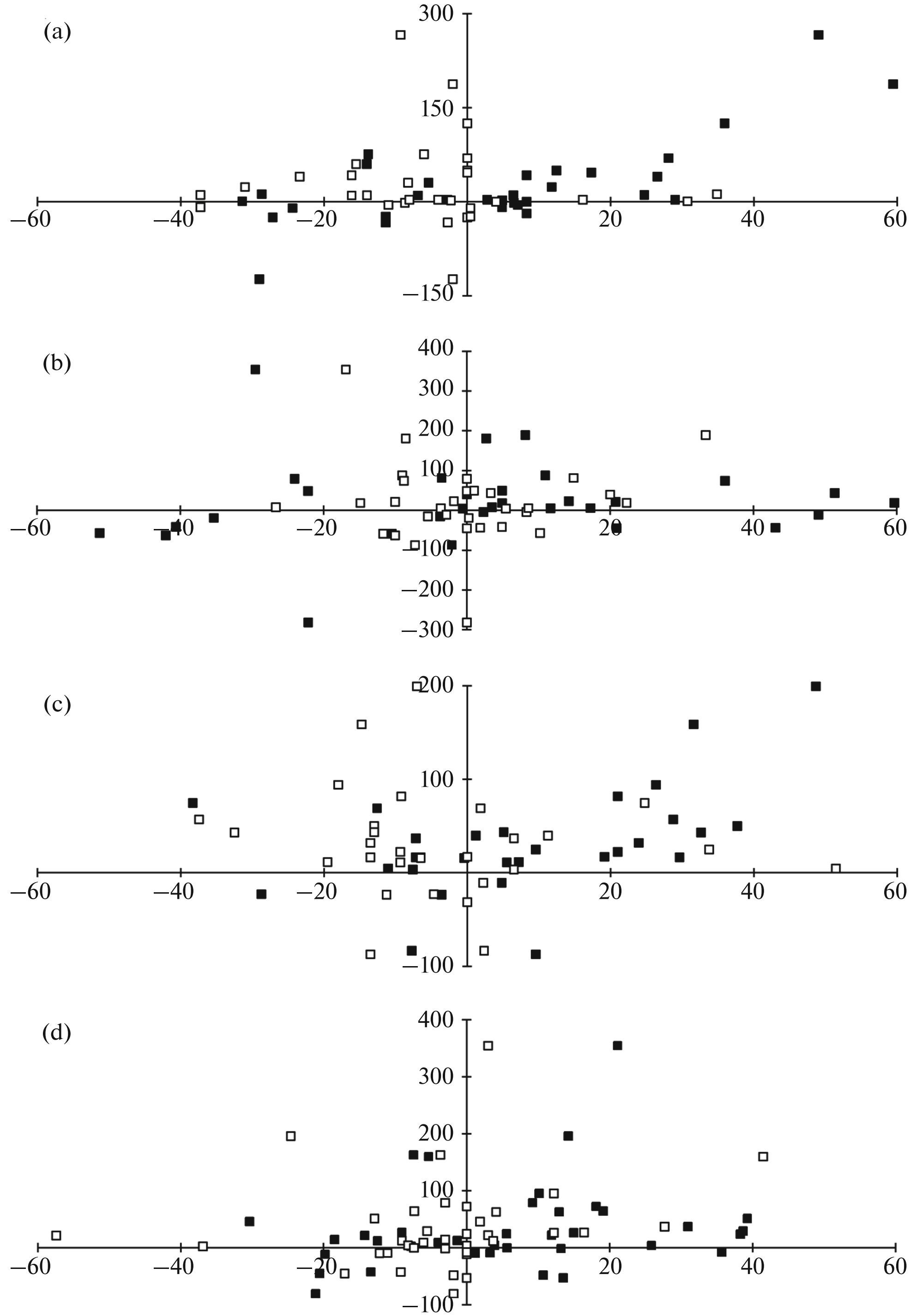

Fig. 6. Variations in rates of dowonstream movement of the juvenile Pink salmon *Oncorhynchus gorb* relative to changes in the water temperature (■) and level (□), estimated by finding the synchronous time deviations of the parameter variables from their previous values for the Bolshaya and Malaya Khuzi Rivers ((a) combined data), the Lazovaya River (b), the Voznesenka River (c), and the Rybatskaya River (d).

matrices, which were recorded with various methods, do not give any good reasons for the denial of impact of study parameters on downstream migration in this case. It has been concluded from the above description of the dynamics of smolt downstream migration for each study river, providing examples of shifting the downstream migration timing to the earlier time in the warm years. Comparing the correlation values calculated based on the actual estimates of parameters can indicate that the patterns of climate in differen regions tend to make reasonable adjustments in the classical type of adjoint varieties in trends in downstream migration (phases of its increase and decrease) and water level and temperature regimes in a river at spring warming trend. In addition, there are random variables in trends in these processes (short-term shifts in weather patterns), causing the lower correlation coefficient values calculated based on parameter-value deviations. Therefore, numerous attempts to associate the changes in the rates of downstream movement with the environmental factors such as river water levels and temperatures, which would seem obvious, do not achieve the expected outcomes. However, these random deviations may be smoothed to some extent at long-term timing of downstream migration, for instance, as in the Rybatskaya River (correspondence of the study correlation coefficient signs to the classical correlation pattern remains, while the strength of these relationships tends to become weaker).

With respect to the different timing of downstream migration in the juvenile Pink salmon, the most commonly reported opininion is associated with a theory that the smolt downstream migratory timing in salmon generations with large numbers of juvenile fish tends to be extended (Volovik, 1967; Shershnev and Zhulkov, 1979; Gritsenko et al., 1987; Karpenko, 1998). However, a critical analysis shows that the smolt downstream migration timing and duration in different years are not strongly ranked based on the proportional factor of numbers (Shuntov and Temnykh, 2008). In addition, the survey-based data on duration of downstream migration of the juvenil Pink salmon in different rivers also do not match the views mentioned above. Moreover, well-expressed reduction in duration of downstream migration in the Pink salmon generations, considered above, at the reference increased numbers of downstream migrants ($r = -0.93$, $n = 4$) is observed for the Iturup Island. However, this association tends to be weaker at the reference increased number of the analyzed generations ($r = -0.30$, $n = 16$). In addition, the adjoint connection between the timing of juvenile fish downstream migration and the duration of the route run stock of parental generations can be observed. For instance, the Pink salmon smolt migration descending the Voznesenka River was, on average, shortest-lasting over the study years (31 nights), while it was the longest-lasting in the Rybatskaya River (48 nights). The migration routes of the Pink salmon of parental generations to the rivers flowing across the southern part of the Southeast Sakhalin Island coast and the Iturup Island could be observed during 71 days and 89 days in 24-hour time format, respectively. Moreover, similarity in the dynamics of these processes (distribution shift in model classes) identified by existence of temporal forms in this Salmon species is recorded based on the data on timing and rates of the Pink salmon migration routes to the Kunashir Island rivers in 1991 and 1994–2010 and the followed smolt downstream migration (Kaev and Romasenko, 2017).

CONCLUSIONS

The downstream mevement rates of the juvenile Pink salmon in all the study rivers tended to increase in the darkest period during each 24-hour day. It was tested by downstream migrant landing sizes at twilight and nighttime of the 24-hour time day, variations in timing of smolt downstream migration along with reducing nighttime of the 24-hour time day, and open data on diurnal downstream migration of this species smolts. The climate patterns of regional variations significantly modify the pattern variations in the smolt number (downstream migratory phases of increased and decreased passage activities) over a season relative to the river temperature and flow regimes under the spring warming conditions. In addition, the regulatory relationships between these variables tend to become weaker under the impact of the short-term weather variations of unsettled patterns relative to its strength and duration.

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ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This work does not contain any studies involving human and animal subjects.

CONFLICT OF INTEREST

The authors of this work declare that they have no conflict of interests.

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