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ZOOPLANKTON, ZOOBENTHOS, AND ZOOPERIPHYTON

Under-Ice Drift of Invertebrates in the Piedmont Part of Kedrovaya River (Primorskii Krai)

V. V. Bogatov and M. V. Astakhov

Institute of Biology and Soil Sciences, Far East Branch, Russian Academy of Sciences, pr. 100-letiya Vladivostoka, 159, Vladivostok, 690022 Russia

e-mail: vibogatov@rambler.ru; mvastakhov@mail.ru

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Abstract—According to quantitative indices, the under-ice drift of invertebrates in the piedmont part of the Kedrovaya River (Primorskii Krai) is lower than during the ice-free period. The winter drift is constituted mainly by Diptera and Ephemeroptera. In the warm season, an active drift of hydrobionts is observed only at night; during the freezing-over period, the drift occurs both at night and in the daytime. The number of daytime migrants prevails over organisms drifting at night. The drift of invertebrates is rather low at twilight. The coming of spring thaw and the appearance of gullies leads to an increase in the abundance of animals in the stream. After the ice breaks up in the river, the larvae of Ephemeroptera return to night-drift activity upon the recession of the flood. However, quantitative indices of the daytime drift of other invertebrate groups remains rather high.

Keywords: invertebrates, Diptera, Ephemeroptera, stream, under ice drift.

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INTRODUCTION

The study of the drift of river benthos (the downstream migrations of invertebrates) is an important issue [4–6, 12, 13, 15, 25, 26, 28–30, etc.]. However, this process has been studied mainly during the vegetation period and the materials presented in international publications concern temperate-climate regions. The necessity of studying the invertebrate migration during the cold period was considered disputable because the opinion existed that the drift of hydrobionts attenuates by the end of autumn [14].

Over the last few years, the first data have been published on the drift of stream invertebrates during the freezing-over period [3, 23, 27]. In the course of studies on the Varzuga (Kola Peninsula) and Shchugor (northern Ural) rivers carried out in early spring, V.N. Shubina and V.G. Martynov [23] observed an intensive under-ice drift of benthic organisms, the taxonomical diversity of which was lower than during the open-water period. The under-ice drift in the Shchugor River was constituted by representatives of Diptera and Ephemeroptera; in the Varzuga River, Diptera, Ephemeroptera, and Plecoptera dominated in the drift. In the Shchugor River there were no differences in the abundance of invertebrates drifting during dark and light periods. In the Varzuga River, 20% of the total diurnal drift occurred under daylight. At the same time, in both rivers, ~90% of the daily biomass of organisms drifted during the nighttime.

I.A. Baryshev and A.E. Veselov [3] studied the seasonal dynamics of drift in the Shuya and Lososinka rivers (Karelia). Based on an analysis of one-time daylight samplings, they came to the conclusion that the abundance of drifting animals in winter is an order less than in summer. Ephemeroptera, Diptera, and Trichoptera were dominant in winter drift.

Pennuto et al. [27] studied the night winter migration of macroinvertebrates in two montane Wyoming streams (United States). It was found that Diptera and Ephemeroptera dominated in drift. Pennuto et al. [27] suggested that there were no differences between day and night drift rates in the streams in winter because of the low light intensity both during the day and at night.

The aim of this work is to study the quantitative characteristics and daily dynamics of the under-ice drift in a typical mountain river in the southern Far East.

MATERIALS AND METHODS

These studies were carried out in the Kedrovaya River, which runs through mountainous terrain in the zone of the coniferous–broad-leaved forests and flowing into the Amur Bay in the Sea of Japan. Its length is 18 km and the catchment area is 45.4 km^2. This river was chosen for two reasons: the Kedrovaya River is not subject to anthropogenic load because it flows through the territory of the Kedrovaya Pad' State Natural Biosphere Reserve and the species structure of invertebrates in the river has been well-studied [1, 9, 11, 16, 17, 19–21 etc.]. In addition, the autumn drift of hydrobionts has been studied earlier [2].

The drift of invertebrates was studied from November 2006 through April 2007 in a typical piedmont river portion. The stream width at the site of observations is 8–12 m, the maximal depth is 0.5–0.6 m, and the ground is formed by gravel and boulder.

The average annual air temperature in the region of studies is 4°C and the average duration of the warm period is 180 days. The winter is rather hard and sunny. In January, the temperature can drop to –36°C [8]. The first ice-covered portions of the river appear at the end of October. The river is frozen over by the first half or in the middle of December. The ice thickness in some parts is ≥0.2 m. The snow cover within the catchment area lies constantly only in narrow valleys and on the northern slopes. Its height is seldom >30–40 cm. The ice in the river usually starts breaking up in April. At the beginning of spring, when it starts thawing, the daily fluctuations in the water level reach 0.3 m. The first half of summer is cool and, as a rule, there are incessant and drizzling rains; the second half of summer is hot with high humidity and an air temperature of ≤40°C. August–September is typhoon season, during which the water level rises by 2 m [10].

During the period of studies, six diurnal series of sampling were made. In order to avoid the effect that moonlight has on the night drift of animals, they were collected in the phase of the new moon: November 20–21 and December 19–20, 2006, and January 19–20, February 16–17, March 19–20, and April 17–18, 2007. In November and April, the samples were collected in the river channel, which was free of ice; in March, unfrozen patches of water were all over the river; and in April the samples were collected during the ebb of the flood. In the course of our work, the water temperature in the river varied from 3.8 to 6.4°C in November, from 0.1 to 0.7°C in winter months, from 0.1 to 3.0°C in March, and from 2.2 to 6.2°C in April. At the site of sampling, the average current velocity in the water column was 0.3–0.4 m/s in November through March and 0.8 m/s in April. During the winter period and in March, the ice on the river was covered with snow (≤0.15 m in height), and only in February did the snow cover exceed 0.6 m.

Drifting organisms were collected by a sampler consisting of three-frame cone-shaped nets joined vertically one above the other. The mesh size of each cone net was 220 μm. The dimensions of the frame were 0.1 m height and 0.25 m width. The exposure time was 300 s. The sampler was set in such way that its total height (0.3 m) was equal to the depth of the water flow. The current velocity was measured using a hydrometric current meter (HCM-55) at three horizons corresponding to the position of each cone-shaped net of the sampler: near the bottom, in the water column, and near the surface layer. The sampling procedures of drifting invertebrates in each diurnal series started and ended at 12:00. During the dark period, the samples were collected every hour. During the light period, the samplings were collected every 2 h. Invertebrate samples were fixed in a 4% solution of formalin. A total of 300 samples were collected and examined.

The number (Nt_i, ind.) of organisms dispersed downstream for 1 h ($t_i = 3600$ s) through a flow section 1 m in width and of a height equal to the height of each horizon of the current (i.e., 1 m × 0.1 m) was determined as follows: Nt_i = (catch, ind./area of the cone mouth, m^2 × current velocity in the cone net, and m/s × time of exposure, s) × (area of the current section, m^2 × current velocity, m/s × 3600 s) This expression is a generalized algorithm of the scheme recommended for the drift studies [6, 7]. The biomass (Bt_i, mg) was estimated by analogy. The integral value of the drift for an hour within an accounting current section (1 m × 0.3 m) was obtained while summing Nt_i or Bt_i for each horizon, and the value of the diurnal drift (ind/day or mg/day) was obtained by the summation of the corresponding characteristics of the drift for each hour. Errors of representativeness of samples of drifting invertebrates were calculated according to N.A. Plokhinsky's manual [18]. The dominant hydrobionts were those animals whose abundance constituted >15% of the abundance (biomass) of the total diurnal drift [11]. The rest of the migrating invertebrates were referred to as "others."

RESULTS

In the Kedrovaya River during the cold season, the larvae of mayflies (Ephemeroptera) dominated in abundance and biomass in the drift. Among them, juvenile Ephemerellidae from the genus *Drunella* and the larvae of Diptera, mainly of chironomids (Chironomidae), prevailed. Mayfly larvae dominated in the drift in November–January and fly larvae dominated in February–April (table). Among other groups of invertebrates, high abundances in some periods were recorded for water mites (Hydracarina), the larvae of stoneflies (Plecoptera) and caddis flies (Trichoptera), oligochaetes (Oligochaeta), and amphipods (Amphipoda). Collembola, Copepoda, Coleoptera, Nematoda (absent in February and March), Oribatida (absent in in January), Heteroptera (absent in November and February) Lepidoptera (found only in March and April), and Ostracoda (recorded only in April) were not numerous. Among terrestrial invertebrates, only aphids (Aphidinea) were consistently present in samples of invertebrates from the under-ice drift (table).

In November–February, the abundance and biomass of organisms drifting from an accounting current section were rather low (~30–80 thousand ind./day and 5–15 g/day, correspondingly (Fig. 1)). The lowest values of quantitative characteristics were recorded in November and January, and the highest values were in December. In addition, a twofold increase in the biomass of migrating invertebrates was recorded in February over January, but their abundance was the same as in January. With the onset of spring, the quantitative indices of the drift increased sharply. In particular, in

Portion (%) of taxonomical groups in abundance (above the line) and biomass (under the line) of the daily drift in the Kedrovaya River in the cold period of 2006–2007

Group	Dates					
	20–21.XI	19–20.XII	19–20.I	16–17.II	19–20.III	17–18.IV
	Aquatic invertebrates					
Diptera	26.8/28.0	15.8/10.2	17.4/15.6	46.4/42.6	53.2/44.7	69.1/51.3
Trichoptera	1.3/5.0	3.3/17.5	1.3/5.5	0.5/7.0	0.1/0.2	1.1/1.8
Ephemeroptera	30.0/32.8	49.8/48.9	56.8/60.4	41.1/21.5	39.4/34.7	20.3/26.0
Plecoptera	1.6/3.2	1.1/3.8	2.1/5.8	3.0/25.3	1.2/8.8	1.9/9.5
Coleoptera	1.3/3.7	0.3/1.2	0.2/0.9	0.5/0.9	0.1/0.1	0.3/1.4
Heteroptera	0	0.1/0.0	0.1/0.0	0	0.1/0.0	0
Lepidoptera	0	0	0	0	0.1/5.7	0.1/0.2
Collembola	3.4/1.7	2.1/0.8	0.1/0.0	2.2/0.4	2.0/0.4	0.4/0.1
Oligochaeta	15.7/15.8	5.9/2.8	2.9/1.8	0.2/0.0	0.9/0.2	1.5/0.3
Nematoda	0.8/0.1	0.4/0.1	0.5/0.8	0	0	0
Amphipoda	0.6/2.7	0.1/7.0	0.2/0.8	0.6/1.6	0.1/4.4	0.4/8.1
Copepoda	0.9/0.4	0.8/0.3	0.5/0.3	1.6/0.1	0.6/0.1	1.4/0.2
Hydracarina	16.4/5.8	20.1/7.2	17.8/7.9	1.6/0.3	1.6/0.3	3.1/1.1
Oribatida	0.2/0.1	0.1/0.1	0	2.1/0.1	0.3/0.0	0.2/0.0
	Terrestrials invertebrates					
Aphidinea	0	0.1/0.1	0.1/0.15	0.2/0.1	0.2/0.1	0
Other groups	1.0/0.7	0	0	0	0.2/0.2	0

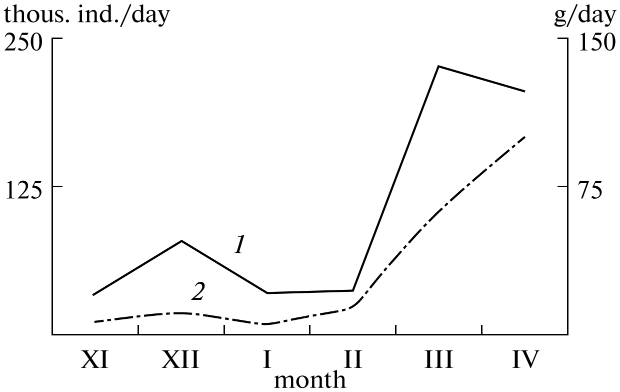

Fig. 1. Dynamics of the invertebrate drift through the accounting flow section of the Kedrovaya River in the cold period of 2006–2007: (*1*) abundance, thous ind./day and (*2*) biomass, g/day.

March the abundance and biomass of animals increased 6.5- and 5-fold over February, correspondingly. In April the abundance of drifting organisms decreased slightly, but their biomass increased eightfold over February (Fig. 1).

It should be noted that, before the freeze up (November samplings), the most active drift of all hydrobiont groups occurred in the first half of nighttime. During diurnal hours, the drift of mayfly and fly larvae had very low rates and was, apparently, occasional, but water mites demonstrated high activity. On average, the total night drift exceeded the diurnal drift of animals 1.6 times in abundance and 2 times in biomass (Figs. 2a, 3a).

In December, after the streams froze over, the pattern of daily activity of hydrobionts changed cardinally (Figs. 2b, 3b). The larvae of flies and other invertebrates, among which water mites prevailed, more actively drifted in the water column under light, with a

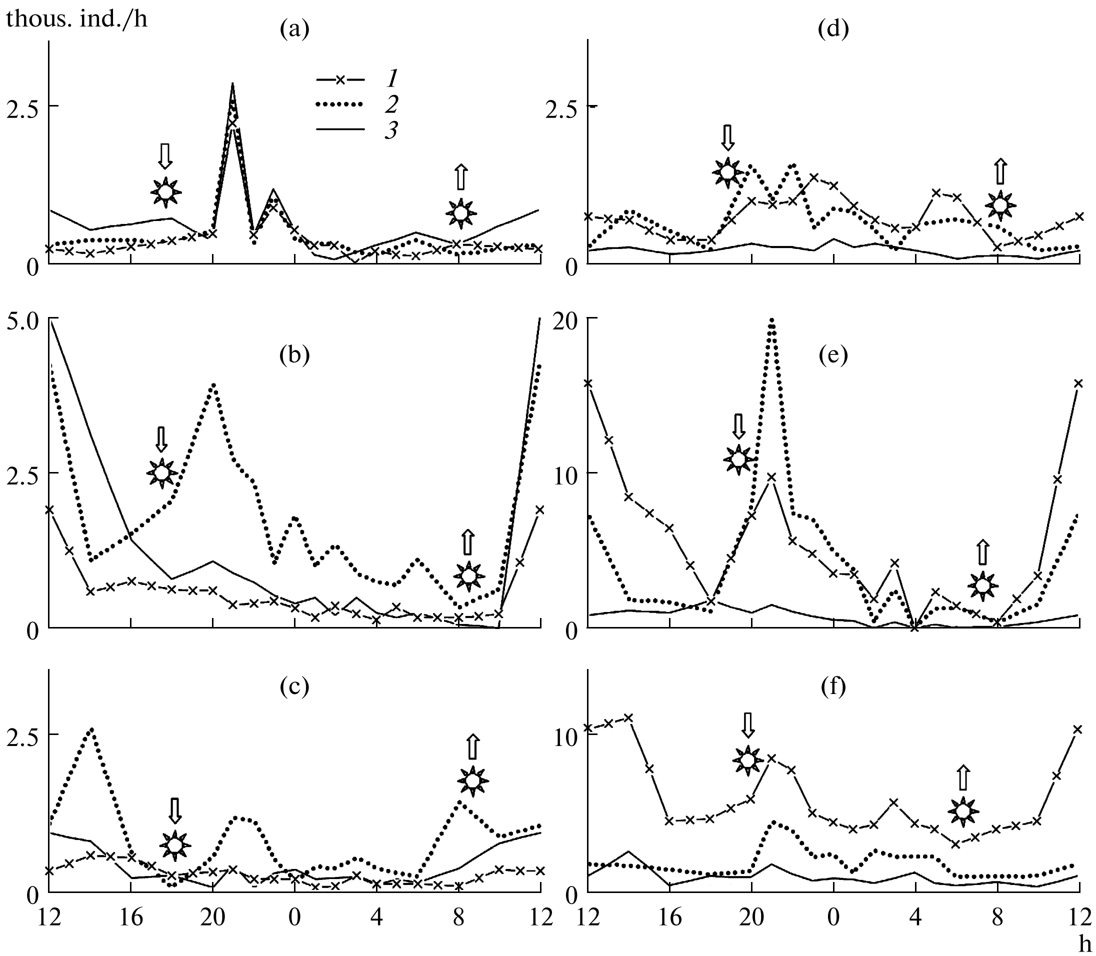

Fig. 2. Daily dynamics of the abundance of drifting invertebrates through the accounting flow section of the Kedrovaya River. Dates: (a) 20–21 Nov. 06, (b) 19–20 Dec. 06, (c) 19–20 Jan. 07, (d) 16–17 Feb. 07, (e) 19–20 Mar. 07, (f) 17–18 Apr. 07; (*1*) Diptera, (*2*) Ephemeroptera, and (*3*) other invertebrates. Arrows indicate the time of sunset and sunrise.

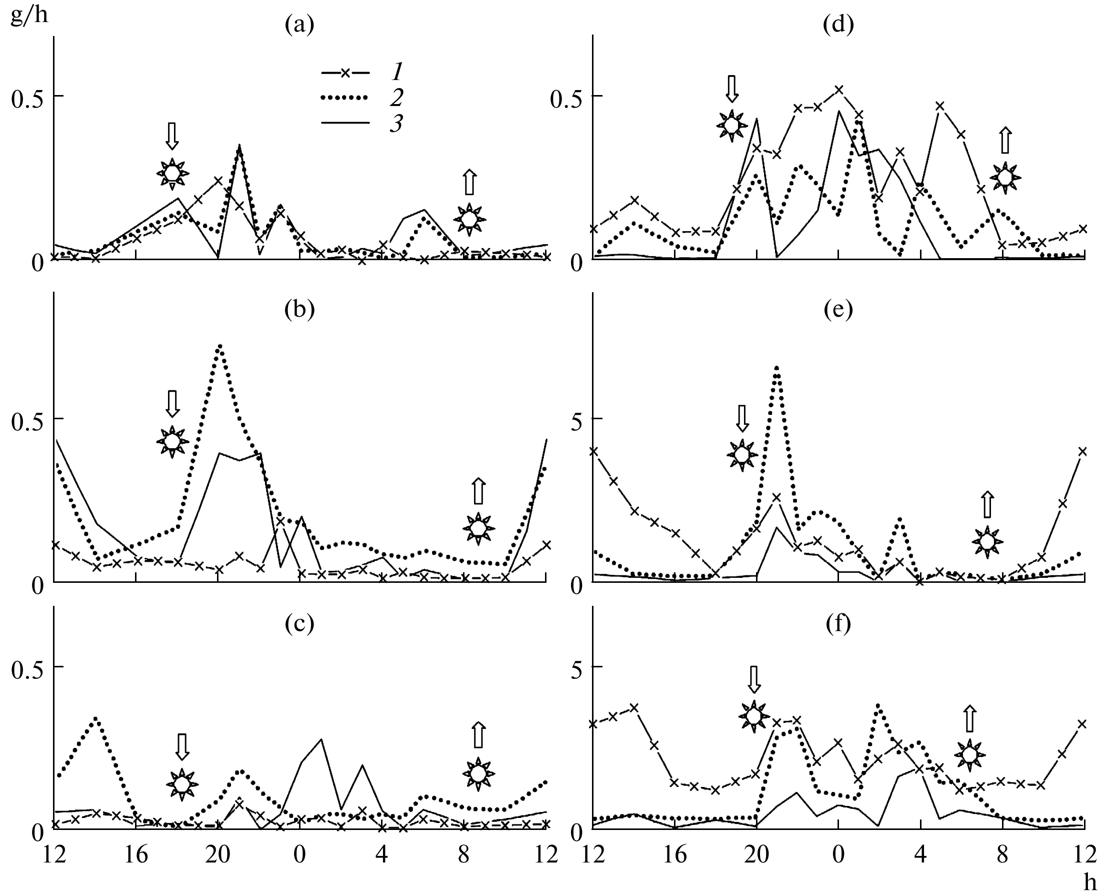

Fig. 3. Daily dynamics of the biomass of drifting animals through the accounting section of the Kedrovaya River. Symbols are the same as in Fig. 2.

peak at 12:00. Mayfly larvae had two expressed peaks of activity: a nocturnal peak with a maximum at 20:00 and a diurnal one with a maximum at 12:00. On the whole, ~58% of the daily abundance of migrating animals fell during the light time. The daytime drift of mayflies constituted ~45% of the daily migration, the larvae of flies and other groups of invertebrates in the daylight drift constituted 63 and 75%, correspondingly (Fig. 4a). The total biomass of the night drift was twice as high as the total biomass of the day drift. The biomass of fly larvae during night and daytime drifts was equal (Fig. 4b).

In January the total abundance of invertebrates that dispersed during the light time was ~2 times larger than in the dark time, but the biomass of the diurnal drift was 1.3 times lower than that of nocturnal drift (Figs. 2c, 3c, 4). It should be mentioned that the biomass of mayfly larvae in the day drift exceeded their biomass in the night drift (Fig. 3c). Among other hydrobionts, water mites had high quantitative parameters of daytime drift.

During our observations in February, because of the heavy snow fall the day before, the height of the snow cover on the ice exceeded 0.6 m, so the light intensity under ice in diurnal hours corresponded to that in the crepuscular period. Under such conditions, the quantitative parameters of the daytime drift of hydrobionts reduced significantly and corresponded to the average values in twilight hours of the previous two winter months (Figs. 2a–2d, 3a–3d). As a result, the total night drift of all invertebrates exceeded the daytime drift 1.7 times in abundance and 4.7 times in biomass (Fig. 4). In February, the larvae of flies and mayflies prevailed in the drift in abundance and the larvae of flies, stoneflies, and mayflies dominated in biomass (table; Figs. 2d, 3d). The share of other groups in the total daily drift was rather low in abundance (<13%) and high in biomass (~36%).

In March, two weeks before ice broke in the river, Ephemeroptera and Diptera, which were dominant in the drift, had two concurring well-expressed peaks of abundance and biomass: a diurnal peak at 12:00 and a nocturnal one at 21:00 (Figs. 2e, 3e). In diurnal drift, the larvae of flies were more abundant and had higher biomasses than in the night drift, but the night drift of mayfly larvae was higher in abundance and biomass

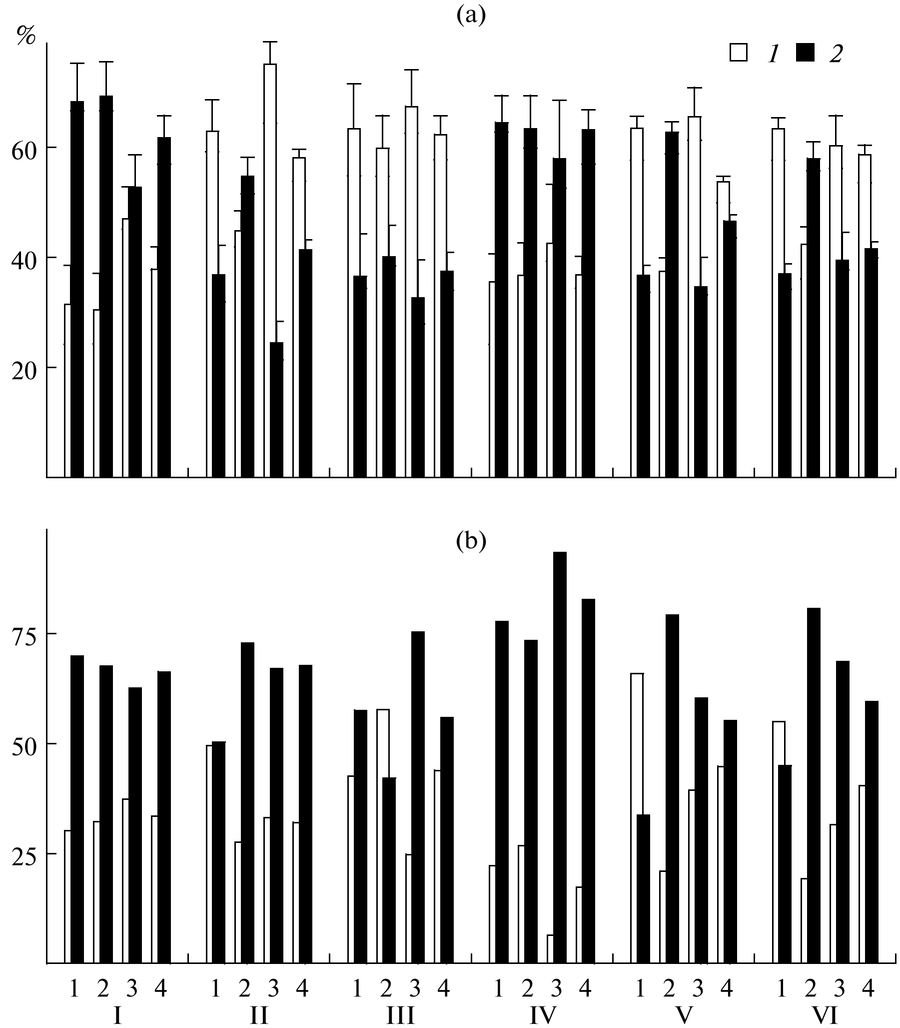

Fig. 4. The portion (%) of the (*1*) day and (*2*) night drift in the daily drift of invertebrates: (a) abundance, (b) biomass; axis of abscissa: (1) Diptera, (2) Ephemeroptera, (3) other groups, and (4) all invertebrates; dates: (I) 20–21 Nov. 06, (II) 19–20 Dec. 06, (III) 19–20 Jan. 07, (IV) 16–17 Feb. 07, (V) 19–20 Mar. 07, (VI) 17–18 Apr. 07. The error of the representativeness of the sampled portion of abundance was calculated at $p \leq 0.05$.

than the daytime drift (Fig. 4). The role of other groups of hydrobionts in the drift was less significant than in February. On the whole, in early spring, the total daily drift of all invertebrates was similar to the night drift according to quantitative parameters.

In April, during a dip in the flood, the diurnal drift of fly larvae was higher than the nocturnal drift in abundance and biomass, but the share of the group in the night drift increased notably (Fig. 4). At the same time, the active drift of mayfly larvae was observed only in dark periods of time (Figs. 2f, 3f). Quantitative indexes of minor groups were relatively low (10.6% of abundance and 22.7% of biomass in the total drift). The diurnal drift of all invertebrate groups continued to be rather high and was 1.4 times more than the night drift in abundance, but the biomass was 1.5 times higher in the night drift (Fig. 4).

DISCUSSION

In the portion of the Kedrovaya River under study in the under-ice drift, there was no significant decrease in the number of systematic groups of invertebrates in comparison to the more northern regions [23]. In particular, in the Kedrovaya River in the cold period of the year (in comparison to September [2]), only Daphniiformes were not recorded in the samples, but Heteroptera (Belostamotidae and Veliidae) appeared; Lepidoptera (Nymphulinae) were found in March. The constant presence of aphids in the drift samples should be mentioned. Apparently, during the freeze-up period, these terrestrial invertebrates could continue their development in thawed patches near water.

In summer in rivers of the southern Far East, the drift of hydrobionts can reach high values. For example, in July at a water discharge of 7.5 m^3/s in a portion of the Pil'da River (Lake Udyl basin, Lower Amur) which is similar to the Kedrovaya River in hydrological characteristics, the total daily drift of only one species of small crustacean *Gammarus* sp. equaled 4.75 kg [5]. During the summers of 1978 and 1979 in the small Ukhta River (width 4 m, depth ≤0.3 m, the Lower Amur basin), the dispersal of *Gammarus* sp. through the accounting section of the flow (1m × 0.3 m) amounted to ~100 g/day [6]. The intensive night drift was documented in the rivers of the Lower Amur basin until September and in the southern regions of the Primorskii krai until October. Insects ended their active downstream migration after the mass emergence of imagoes and amphipods dominating in the autumn drift due a sharp decrease in motional activity [2, 6]. With the appearance of wintering generations of insects, the intensity of the night drift of hydrobionts increased again [2]. However, in the Kedrovaya River in November, as well as throughout the whole winter period, the winter drift of hydrobionts was less intensive than in the warm period of the year and the migration through the accounting section area of the flow (1 m × 0.3 m) was 10 g/day. With the coming of spring thaws and the appearance of gullies, the abundance and biomass of migrating invertebrates increased notably.

In the warm period of the year, the overwhelming number of bottom organisms migrated downstream during night hours [6, 24]. The studies conducted by these authors have shown that, after the rivers froze over, more hydrobionts started their drift in the daytime. In particular, in December, the diurnal drift of fly larvae exceeded the nocturnal drift. The daytime drift of mayfly larvae also increased in December, and in January the quantitative values of the daytime drift of mayflies exceeded the values of the night drift. Among other groups of hydrobionts, an active under-ice drift in the daytime was observed for water mites. Despite the high daytime activity of the larvae of flies, mayflies, and water mites, the total mass of invertebrates drifting in the dark was higher than under light (table; Fig. 4) This supports the opinion of Shubina and Martynov [23] that, during the freeze-up period, the main portion of invertebrate biomass is dispersed at night. Apparently, the domination of adult individuals in the night drift of animals is a common property of rheobionts from different regions. It should be mentioned that, in the first spring months, most hydrobionts manifest higher activity at night and the larvae of mayflies return to night activity during the flood.

In the cold time of the year, the authors did not observe an evident crepuscular drift of hydrobionts, although in summer some invertebrates could be intensively dispersed downstream in the twilight [6]. The formation of crepuscular conditions in the river during the light time of the day (due to the formation of a thick snow cover) reduced the diurnal drift of hydrobionts, and its quantitative parameters were lower that in the night drift. This confirms the importance of light as one of the most important factors controlling the drift intensity. In addition to that, the high diurnal activity of most hydrobionts in the cold time of the year apparently depends on the low feeding activity of fish.

One typical feature of the cold period of the year is the increasing role of flies in the drift (table). In spite of the considerable difference (4.5 h) between the duration of the light time in December and April, the relationship between the values of the day and night drift for Diptera did not vary (Fig. 3). The deceleration of metabolism processes in winter probably smoothed the differences in larvae with different behavioral activities (day and night), so the constant correlation of flies in the day and night drifts remained throughout the cold period. Apparently, the intensification of the downstream migration of fly larvae in the ice period is caused by the changing requirements for the environmental conditions and a search for new biotopes of growing hydrobionts. In addition, the high diurnal activity of Diptera in spring months was determined by their emergence features. An increase in the activity of flies during the daytime drift in the spring was observed by V.V. Chebanova [22].

CONCLUSIONS

In the Kedrovaya River, invertebrate drift was observed during the cold period of the year, but the intensity of the under-ice drift was lower than in the open water period. The under-ice drift was mainly constituted by Diptera and Ephemeroptera and, partially, by Hydrocarina and Plecoptera. The daily rhythms of their ascension to the water column were preserved under ice at the minimal daily fluctuations of light intensity. In contrast to the warm period of the year, with high migration activity and an intensive drift of hydrobionts in the dark time of the day, during the freeze-up period the animals ascended to the water column both at night and during the day and their abundance in the day drift was higher then at night. Under conditions of a thick snow cover, the portion of diurnal migrants in the daily drift decreased notably. The drift of animals was low in twilight. In spring, with the appearance of thawed patches, the abundance of drifting organisms in the water flow increased to a great extent. After the ice broke up in the river, the larvae of mayflies started their drift at night, even during a dip in flooding. The quantitative parameters of the daytime drift for other invertebrate groups remained at a rather high level.

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