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By E.L. Afanas'eva

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in Lake Baikal estimated by different methods

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(The V.I. Lenin Belorussian State University,
recipient of the Red Banner of Labour).

COMPARISON OF THE VALUES OF THE PRODUCTION OF
EPISCHURA BAICALENSIS SARS. IN LAKE BAIKAL

ESTIMATED BY DIFFERENT METHODS UNEDITED DRAFT TRANSLATION

Only for information

E.L. Afanas'eva

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(Limnological Institute of the Siberian Division
of the Academy of Sciences of the USSR)

Epischura baicalensis S a r s. (Copepoda, Calanoida) occupies a leading position in the plankton of Lake Baikal, constituting up to 90% of its numerical strength and biomass. This *rachok* (crablet!)* serves as the principal food item of fish and of the predatory invertebrates of the palagic assemblage of the lake, being a phytophagous and bacteriophagous filterer.

It has been possible to undertake the calculation of this crablet's production only after the elucidation of certain questions concerning its biology. As data for this have served perennial observations at the *dekadnaya*# station in the open part of southern Baikal for the layer 0-250 metres. The processing of the data was done taking cognizance of the numerical strength and biomass of the individual stages of the development of the *Epischura*. More than 500 ovaries of females were dissected, in which all oocytes were counted. More than 1300 measurements of adult specimens were done.

As a result, we have determined the number of *Eposchura* generations in a year, the duration of metamorphosis and the life span of adult specimens of each generation, the fertility of the females and the ratio of the sexes (Table 1).

Calculation of the production of *Epischura* has been done separately for crablets of the winter and summer generations, which, developing under different ecological conditions, are distinguished by morphological peculiarities, and differ in the duration of the development of individual stages, and in the life spans of adult specimens, *et cetera*.

* Italic brackets () enclose translator's parentheses.

Usually means "a decade of days", and sometimes "decimal", but is cryptic in this context. Translator

One year's production of *Epischura* has been determined by a number of methods, namely: by the graphic method, variant I (Vinberg, Shushkina and Pechen', 1965), by formula (Pechen', Shushkina, 1964), by the graphic method, variant II (Greze and Baldina, 1964) and by the method of B.M. Mednikov (1962).

Below will be given the calculation of the value of the *Epischura's* production for the winter generation (from February to June, 1962)¹ by the enumerated methods. Shown in Table 1 are certain data on the biology of the *Epischura* of the winter generation which are necessary for calculation of its production.

[195]

C a l c u l a t i o n b y t h e g r a p h i c
m e t h o d o f G . G . V i n b e r g (F i g u r e 1) :

The growth curve (Figure 1a) was plotted according to the initial weights of the individual stages of development. After attaining sexual maturity, the *Epischura* does not grow; and its weight remains constant. On the basis of the growth curve, a curve of absolute growth increment was plotted (Figure 1b). For this purpose, the values of the weight of the specimen (W_0 and W_t) at the instants t_0 and t were taken off the growth curve. The value of the mean absolute growth increment for the intervals (1-15 days) was found from the formula:

$$p = \frac{W_t - W_0}{t - t_0}$$

When constructing the increment curve, the quantity p was plotted in the middle of the interval $t - t_0$.

When constructing the curve of numerical strength, the mean numerical strength of the daily ages of the given stage was plotted against

¹ There are no data for January, 1962. (Author)

the point on the abscissa corresponding to the mean duration of the stage (Figure 1c).

The values of the mean daily increment of the specimens and their numerical strength were taken from the appropriate curves. From their products were obtained the productions of the individual ages, on the basis of which the production curve (Figure 1d) is constructed. The area bounded by the curve gives the mean daily production of the generation due to juveniles. [196] The production of adults from eggs was calculated on the basis of the egg-laying tempo and the biomass of the eggs:

$$\frac{q}{D_e} \cdot J \cdot x \cdot R,$$

where q is the weight of an egg; D_e is the duration of embryonic development; J is the number of adults; x is the percentage of the total number of adults which are females; and R is the number of eggs in one laying. Adding the production of adults from eggs to the production of juveniles, we obtain [197] the total production of the winter generation per day. Multiplying this production by 150 days, we obtain the production of the winter generation for the period from February to June.

The results of these calculations are given in Table 2.

Calculation by formula (Pechen', Shushkina, 1964):

$$P = \left[\frac{q}{D_e} jxR + \frac{k-n}{D_n} N + \frac{i-k}{D_k} K \right] \cdot t,$$

where q, n, k, i are the initial weights of the eggs, nauplius larvae, copepodites and adults, respectively; N, K, J are the numerical strengths of the nauplius larvae, copepodites and adults, respectively; D_e, D_n, D_k are

[198]

the durations of the embryonic, naupliar and copepodital periods; x is the percentage of the total number of adults which are females; R is the number of eggs *per* laying *per* female; and t is the observation time in *days*.

In order to obtain the production of the winter generation of *Epischura*, we used average monthly ^{data} on the numerical strength of the individual stages of development and of adult *Copepoda*#, derived from the ten-day* observations at the permanent station.

C a l c u l a t i o n b y t h e g r a p h i c
m e t h o d (v a r i a n t I I) (F i g u r e s 2, 3):

The growth curve was constructed on the basis of the initial and average weights of the individual stages of development, and the initial weight of adult specimens (Figure 2). After the attainment of sexual maturity, the growth of the *Copepoda*# stops, and the process of reproduction of the living substance proceeds by way of egg-formation. This is shown by the dotted line on the figure. The female *Epischura* may give 200 eggs during her lifetime, which constitute $50 \cdot 10^{-3}$ *milligrammes*.

In Figure 3, curve (a) shows the tempo of the growth increment of one specimen as a function of its weight. Curve (b), showing the dependence of numerical strength on weight, was constructed in the following manner: on the horizontal axis was plotted the maximum weight of nauplius larvae, copepodites and adult specimens, taking into account the production of their eggs; on the vertical axis was plotted the average numerical strength of the nauplius larvae, copepodites and adults as a cumulative total. Then, depending

In retrospect it seems that *rachok*, literally "crablet", should have been rendered by *Copepoda* throughout this translation.

Translator

* Footnote# on page 2 is rescinded. Translator.

on the paths of the curves, Figure 3 (a,b) was divided by verticals on the section (Sic). For each vertical was determined the number of specimens [199] (n_1, n_2, \dots, n_n) having a weight within the limits bounded by neighbouring verticals. The obtained values of n were multiplied by the average values of the growth increment for the given section, which were taken from the curve (a). The production was reckoned by summing the obtained products for all sections of the graph (Figure 3).

C a l c u l a t i o n b y m e t h o d o f
B. M. M e d n i k o v a. This method is suitable for determining the production of a stationary population. It has been used for the *Copepoda Epischura*, which gives two generations per year. The calculation is done separately for each generation. The annual value of the production of the *Epischura* was obtained by summing the values for the winter and summer generations.

For the initial number of females giving the winter generation, we took the average number of them for the period from October, 1961, to February, 1962, which was equal to 31,000 *specimens/metre*². For a fertility of 66 (the product of the average number of eggs in the egg-sac and the average number of layings which the female can give under ordinary conditions), the initial numerical strength of the winter generation (N_0) will be equal to 2,046,000 *specimens/metre*². For the final numerical strength of this generation was taken the number of *Copepoda* of the fifth copepodite stage and adult specimens in June, 1962, (N_t), equal to 162,400 *specimens/metre*². [200]

The coefficient of elimination was calculated using the formula:

$$N_0 e^{-kn} = N_t,$$

where $k = (\log_e N_0 - \log_e N_t) \div n +$,

and n = the duration of the life of nauplius larvae, copepodites
and adult *Copepoda*, i.e. $n_1 + n_2 + n_3 = 270$ days;

moreover, the average age of adult specimens was taken as 90 days ($180 \div 2$),
as old and young females were encountered in equal numbers in the plankton.

$$P(*) = N_0 \cdot [(1 - e^{-kn}) \cdot v_1 + (e^{-kn} - e^{-k(n_1+n_2)}) \cdot v_2 + (e^{-k(n_1+n_2)} - e^{-k(n_1+n_2+n_3)}) v_3] = 33.5g/m^2, \quad [201]$$

whereas for the period from February to June (150 days): $P=18.0$ grammes/metre²;

P/B average for the period = 5.0; P/B daily = 0.033.

Thus, the results obtained by the four methods turned out to be comparatively close (Table 4).

Consequently, knowing the fundamentals of the biology of *Copepoda* (the duration of the development of the individual stages, the life span of adult specimens, the number of egg-layings which a female can perform during her lifetime, the average number of eggs in the egg-sac, the ratio of the sexes, the number of generations, and the possibility of somehow dividing them, the weights of the individual stages of development, and their numerical strength for definite intervals of time), one may calculate the production of species which are of interest by any of the above-enumerated methods.

+ This relation, in conjunction with the equation at the foot of
of the preceding page, implies that: $l = l$. Translator

* Winter generation. (Author)

B I B L I O G R A P H Y

- 1 Afanas'eva, E. L., 1960.

Naupliial'nye stadii rachka iz ozera Baikal.

(The naupliial larvae stages of *Copepoda* from Lake Baikal)

Izv. Sibirsk. otd. AN SSSR, 8.

(Bulletin (*Izvestiya*) of the Siberian Division
of the Academy of Sciences of the USSR, 8)

- 2 Vinberg, G.G., Pechen', G.A., Shushkina, E.A., 1965.

*Produktsiya planktonnykh rakoöbraznykh v trëkh ozërach
raznogo tipa.*

(The production of planktonal *Crustacea* in three lakes
of different types)

Zoöl. zh., 44, 5: 676-687.

(Zoological Journal, 44, 5: 676-687)

- 3 Greze, V. N., Baldina, E.P., 1964.

*Dinamika populyatsii i godovaya produktsiya Acartia
clausi i Centropages kröyeri v nerëticheskoi zone
Chërnogo morya.*

(The population dynamics and annual production of
Acartia clausi and *Centropages kröyeri* in the neritic
zone of the Black Sea)

Tr. Sevastop. biol. st., 17: 249-261.

(Proceedings (*Trudy*) of the Sevastopol'
Biological Station, 17: 249-261)

4 K o z h o v, M. M., 1965.

K poznaniyu planktona ozera Baikal.

(Contribution to the knowledge of the plankton of Lake Baikal)

Izv. BGNI pri Irkutskom un-te, 18: 1-2.

(Bulletin (*Izvestiya*) of the BGNI* associated with Irkutsk University, 18: 1-2)

5 M e d n i k o v, B. M., 1962.

O prodolzhitel'nosti metamorfoza veslonogikh rachkov (Calanoida) i opredelenie produktsii vidov c rastyanutym periodom razmnozheniya.

the
(On the duration of the metamorphosis of†sub-class Copepoda (*Calanoida*) and determination of the production of species having a drawn-out breeding period)

Okeanologiya, 2, 5: 881-887.

(Oceanology, 2, 5: 881-887)

6 P e c h e n ' , G. A., S h u s h k i n a, E. A., 1964.

Produktsiya planktonnykh rakoöbraznykh v ozërah raznogo tipa.

(The production of planktonal *Crustacea* in lakes of different types)

Biologicheskie osnovy rybnogo khozyaistva na vnutrennykh vodoëmakh Pribaltiki: 249-256. Minsk.

(The biological principles of the fisheries on the inland water reservoirs of the Baltic Sea area: 249-256. Minsk)

* Cryptic. NI probably stands for *nauchnyi institut* = Sci. Inst. Translator.

Calculation of the production of *Epischura baicalensis* by the graphic method of G.G. Vinberg:

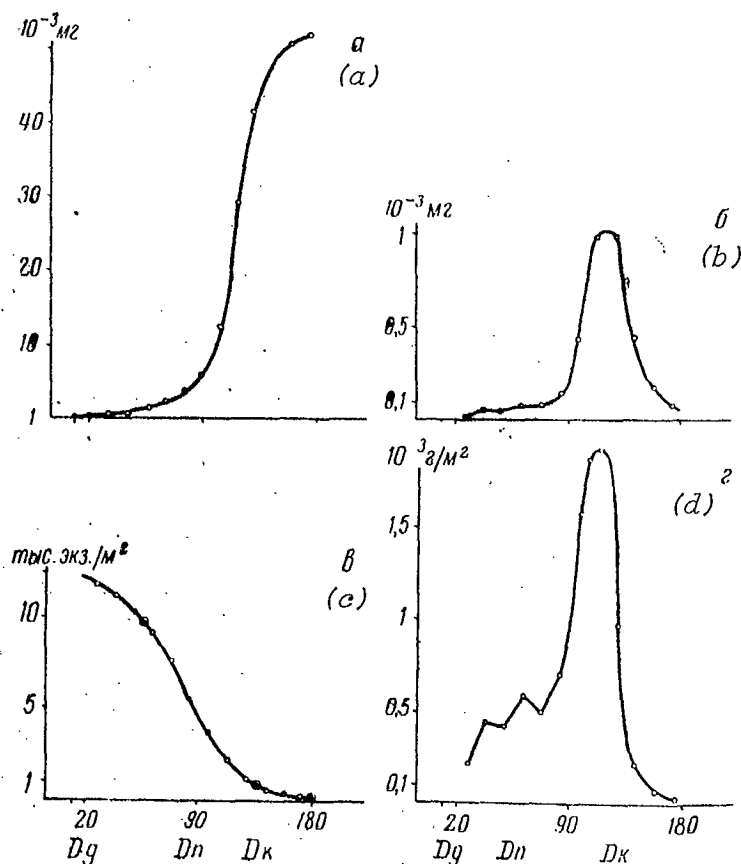


Рис. 1. Расчет продукции *Epischura baicalensis* графическим методом Г. Г. Винберга (по оси абсцисс — продолжительность развития (сутки)):

a — кривая роста особи (по оси ординат — вес особи в 10^{-3} мг); *b* — кривая абсолютного прироста (по оси ординат — прирост особи в 10^{-3} мг); *c* — кривая численности возрастов (по оси ординат — численность в тысячах экз. земляров на кв. метр); *d* — кривая продукции возрастов (по оси ординат — продукция в миллиграммах на кв. метр в сутки).

- a* Growth curve of the specimen (Ordinate: weight of specimen in 10^{-3} mg).
- b* Absolute increment curve (Ordinate: growth increment of the specimen in 10^{-3} milligrammes).
- c* Curve of the numerical strength of ages (Ordinate: the numerical strength in thousands of specimens per square metre).
- d* Curve of the production of ages (Ordinate: the production in milligrammes per square metre per day).

A b s c i s s a (in all cases): Duration of development (days).

Figure 3.

[199]

Calculation of the production of *Epischura baicalensis* by the graphic method of V.N. Greze. Numerical strength and intensity of the growth increment:

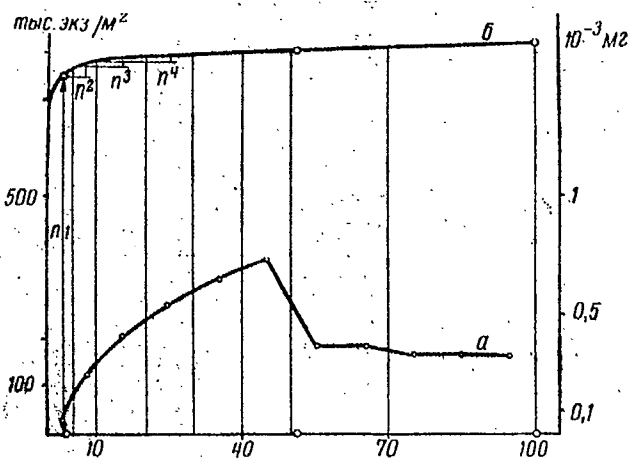


Рис. 3. Расчет продукции *Epischura baicalensis* графическим методом В. Н. Грече. Численность и интенсивность прироста: а — кривая темпа прироста одной особи в зависимости от ее веса (на оси абсцисс — вес особи в 10^{-3} мг, а на оси ординат — суточный прирост в 10^{-3} мг); б — кривая зависимости численности от веса (на оси абсцисс — максимальный вес науплиусов, копепоидитов и взрослых с учетом продукции их яиц, на оси ординат — нарастающим итогом численность науплиусов, копепоидитов и взрослых в тысячах экземпляров на кв. метр, n_1, n_2, \dots, n_n — количество особей, имеющих вес в пределах, ограниченных соседними вертикалями в тысячах экземпляров на кв. метр).

a Curve of the tempo of the growth increment of one specimen as a function of its weight (Abscissa: weight of the specimen in 10^{-3} milligrammes. Ordinate: daily increment in 10^{-3} mg).

b Curve of the dependence of numerical strength on weight (Abscissa: The maximum weight of nauplius larvae, copepodites and adults, taking into account the production of their eggs. Ordinate: Cumulative total of the numerical strength of nauplius larvae, copepodites and adults in thousands of specimens per square metre. n_1, n_2, \dots, n_n are the number of specimens having a weight within the limits bounded by the neighbouring verticals, in thousands of specimens per square metre).

Left-hand ordinate: Thousands of specimens/metre². Translator

Right-hand ordinate: 10^{-3} milligrammes. "

Table 1.

[195]

Certain data on the *Epischura baicalensis* Sars. of the winter generation¹:

Author	Object:	α days	W e i g h t:		Average Numerical Strength		Mean biomass for the period g/m ²	δ
			Initial mg·10 ⁻³	Average mg·10 ⁻³	For the period: β	Of daily ages: γ		
§	Nauplius larvae	90 (Dn)	0.25 (n)	1.5 (v ₁)	856.43	9.52	-	-
¶	Copepodites	90 (Dk)	5.5 (k)	22.0 (v ₂)	54.25	0.60	-	-
¶	Adult Copepoda	180 (Di)	51.0 (i)	- (v ₃)	*12.54	0.14	-	-
	Eggs	20 (Dq)	0.25 (q)	-	-	-	-	200
	All Copepoda	-	-	-	923.22	-	3.59	-

The average number of eggs in the egg-sac of the female is 22 (R).

The ratio of the sexes is close to unity (x).

The interval between two egg-layings is 20 days (De).

¹ The development of the *Copepoda* of the winter generation takes place at a mean temperature of $\approx 2.61^{\circ}\text{C}$, and of the summer generation, $\approx 4.97^{\circ}\text{C}$.
(Author)

Key to symbols:

§ Afanas'eva, 1960.

¶ Kozhov, 1965.

α The durations of the periods of development of *Copepoda* and of the adult period.

β Thousands of specimens / metre².

γ Thousands of specimens / metre².

δ Fertility of the females (the average number of oocytes in the ovary).

* $\frac{0}{\ddagger}$ - 6.76.

The average monthly production of the *Epischura baicalensis* population, calculated by the graphic method (variant I):

Weight of a specimen $mg \cdot 10^{-3}$	Growth increment $mg \cdot 10^{-3}$	Numerical strength of ages $10^3 \frac{\text{specimens}}{\text{sq. metre}}$	Value of the production of ages $mg \cdot 10^{-3}$
0.25	0.017	11.6	0.2
0.5	0.04	10.9	0.44
1.0	0.04	10.0	0.42
1.5	0.066	9.0	0.59
2.5	0.066	7.5	0.49
3.5	0.13	5.3	0.69
5.5	0.43	3.6	0.57
12.0	0.96	2.0	0.92
26.5	0.96	1.0	0.96
41.0	0.43	0.5	0.21
47.5	0.16	0.3	0.05
50.0	0.066	0.15	0.01
51.0			

Mean daily production due to juveniles¹, $grammes/metre^2$ = 0.11144

Production of adults due to eggs: $\frac{q}{D_e} \cdot Q \cdot R$, $g/metre^2$ = 0.00186 (per day)

Total production per day, $grammes/metre^2$, = 0.1133

Production of the winter generation, $grammes/metres^2$ = 16.995

P/B , average for the period, = 4.7

P/B , daily, = 0.031

¹ The mean daily production of the *Epischura* due to juveniles is the integral of the curve of production of ages. (Author)

Table 2a*

Months	I - II,	II - III,	III - IV,	IV - V,	V - VI
P , g/m^2	1.1903	2.754	2.2044	3.3151	2.847

Production of the winter generation, g/m^2 , = 12.311

P/B , average for the period, = 3.3

P/B , daily, = 0.023

* This table is not numbered in the text, but is directly below Table 2. Translator

T a b l e . 3.

[200]

The daily production of *Epischura baicalensis* calculated by the graphic method (variant II):

Weight group $mg \cdot 10^{-3}$	Mean daily growth increment of a specimen (v) $mg \cdot 10^{-3}$	Numerical strength (n) $10^3 \frac{\text{specimens}}{\text{sq. metre}}$	Daily production (nv) $mg/metre^2$
0 - 5	0.055	856	47.08
5 - 10	0.256	15	3.84
10 - 20	0.416	14	5.82
20 - 30	0.55	10	5.50
30 - 40	0.66	10	6.60
40 - 50	0.74	10	7.40
50 - 70	0.37	5	1.85
70 - 101	0.37	5	1.65
T o t a l:		925	79.74

Daily production, *grammes per square metre per day*, = 0.08

Production for the period, *grammes per square metre*, = 12.0

P/B, average for the period, = 3.3

P/B, daily, = 0.022

Table 4.

The seasonal production and P/B coefficients of the winter generation of *Epischura baicalensis*, calculated by different methods:

Method:	$B \text{ g/m}^2$	$P \text{ g/m}^2$	P/B for the season:	P/B daily:
Graphic (variant I):	3.59	16.99	4.7	0.031
Formula of G.A. Pechen' and E.A. Shushkina:	3.59	12.27	3.3	0.023
Graphic (variant II):	3.59	12.0	3.3	0.022
of B.M. Mednikov:	3.59	18.0	5	0.033
Average value:		↓ 14.8 ±3	↓ 4.07 ±0.89	

XEROX COPIES OF THE TABLES

Table 1.

Таблица 1
Некоторые данные биологии *Epischura baicalensis* Sars. зимнего поколения¹

Объект	Сроки развития рачков и жизнь взрослых, сутки	Веса		Средняя численность		Средняя биомасса за период, г/м ²	Плодовитость самок (ср. кол-во ооцитов в яичнике)
		начальные, мг. 10 ⁻³	средние, мг. 10 ⁻³	за период, тыс. экз./м ²	каждодневных возрастов, тыс. экз./м ²		
Науплиусы	90 (Dn)	0,25 (n)	1,5 (v ₁)	856,43	9,52	—	—
		(Афанасьева, 1960)					
Копеподиты	90 (Dk)	5,5 (k)	22,0 (v ₂)	54,25	0,60	—	—
		(Кожов, 1965)					
Взрослые рачки	180 (Di)	51,0 (i)	— (v ₃)	12,54	0,14	—	—
		(Кожов, 1965)		(♀—6,76)			
Яйца	20 (Dq)	0,25 (q)	—	—	—	—	200
Все рачки	—	—	—	923,22	—	3,59	—
Среднее число яиц в яйцевом мешке самки — 22 (R)							
Соотношение полов близко к единице (x)							
Интервал между двумя кладками — 20 суток (De)							

¹ Развитие рачков зимнего поколения происходит при средней температуре ~ 2,61°, а летнего ~ 4,97°.

Table 3.

Таблица 3
Суточная продукция популяции *Epischura baicalensis*, рассчитанная графическим методом (II вариант)

Весовая группа, мг. 10 ⁻³	Средний суточный прирост особи (v), мг. 10 ⁻³	Численность (n), тыс. экз./м ²	Суточная продукция л/в, мг/м ²
0—5	0,055	856	47,08
5—10	0,256	15	3,84
10—20	0,416	14	5,82
20—30	0,55	10	5,50
30—40	0,66	10	6,60
40—50	0,74	10	7,40
50—70	0,37	5	1,85
70—101	0,37	5	1,65
Всего . . .		925	79,744
Суточная продукция, г/м ² сутки			0,08
Продукция за период, г/м ²			12,0
P/V средний за период			3,3
P/V суточный			0,022

Таблица 2

Среднесуточная продукция популяции *Epischura baicalensis*,
рассчитанная графическим методом (I вариант)

Вес особи, мг · 10 ⁻³	Прирост, мг · 10 ⁻³	Численность возрастов, тыс. экз./м ³	Величина продукции возрастов, мг · 10 ⁻³
0,25	0,017	11,6	0,2
0,5	0,04	10,9	0,44
1,0	0,04	10,0	0,42
1,5	0,066	9,0	0,59
2,5	0,066	7,5	0,49
3,5	0,13	5,3	0,69
5,5	0,43	3,6	0,57
12,0	0,96	2,0	0,92
26,5	0,96	1,0	0,96
41,0	0,43	0,5	0,21
47,5	0,16	0,3	0,05
50,0	0,066	0,15	0,01
51,0			

Среднесуточная продукция за счет молодежи ¹ , г/м ²	— 0,11144
Продукция взрослых за счет яиц $\frac{q}{D} \cdot \varphi \cdot R$, г/м ²	— 0,00186
Общая продукция за сутки, г/м ²	— 0,1133
Продукция зимнего поколения, г/м ²	— 16,995
P/V средний за период	— 4,7
P/V суточный	— 0,031

¹ Среднесуточная продукция эпишуры за счет молодежи — интеграл кривой продукции возрастов.

Месяцы	I—II,	II—III,	III—IV,	IV—V,	V—VI
P, г/м ²	1,1903	2,754	2,2044	3,3151	2,847
Продукция зимнего поколения, г/м ²				—	12,311
P/V средний за период				—	3,3
P/V суточный				—	0,023

Table 4.

Таблица 4

Сезонная продукция и P/V-коэффициенты зимнего поколения
Epischura baicalensis, рассчитанные разными методами

Методы	Z г/м ²	P г/м ²	P/V за сезон	P/V сутки
Графический (I вариант)	3,59	16,99	4,7	0,031
Формула Г. А. Печень, Э. А. Шуш-Кинной	3,59	12,27	3,3	0,023
Графический (II вариант)	3,59	12,0	3,3	0,022
Б. М. Медникова	3,59	18,0	5	0,033
Среднее значение	14,8 ± 3		4,07 ± 0,89	