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Vertical Zoning of Tien Shan Mountain Streams, in Terms of the Distribution of Representative Water Insects

K. A. Brodskiy and E. O. Omorov

Six vertical zones were identified in Tien Shan mountain streams based on the distribution of representative aquatic insects (mainly Ephemeroptera, Trichoptera, and Diptera). This distribution is typical of streams flowing from the slopes of mountain ranges and of intermontane streams. They differ from one another in the length of such zones.

The earlier notion that a knowledge of the invertebrate fauna of mountain streams is only of theoretical value (for study of the adaptation of organisms to living in rapidly flowing waters) [19, 27, 28] was refuted by practical experience. It is no accident that the attention of hydrobiologists in Western Europe and the United States has been focused on flowing and especially rapidly flowing streams. Rhytobiology is now swiftly developing in many countries [31].

In the USSR, the study of mountain streams was initiated by a detailed investigation of a typical stream in the northern Tien Shan [1]. The data were published only in part; the unpublished data are included in this article. Analysis of mayflies and Diptera characteristic of streams showed that almost all of them were new, endemic of the Tien Shan, whether of species or genus rank [2, 22, 24]. The endemic nature of the fauna of the Tien Shan streams was subsequently confirmed for other groups of organisms [5, 7, and others]. Since several Tien Shan rivers and streams have been fairly completely studied by now [1, 12, 16, 18], their faunas can be compared. We do not intend to discuss here another Central Asian region, adjacent to the Tien Shan, namely the Western Pamir region and the Pamirs, where the upper reaches of the Amu-Dar'ya have been investigated [4].

The large-scale construction of reservoirs in the USSR, adaptation of fish in rivers, streams, and canals of the irrigation system, the pure water problem, and, finally, the use of organisms in rapidly flowing streams, as indicators of their hydrobiological conditions – all these things make it necessary to study invertebrates, fishes, and especially the ecological characteristics of individual species from mountain streams.

The available data on the feeding of local fishes in the Tien Shan streams clearly indicate that their basic food are the characteristic and widespread forms: mayflies, caddis flies, chironomids, gnats, and net-veined midges (our information was derived from a study of fishes in the Chirchik, Zeravshan [14, 16], and Ak-Bura river systems). These insects are the typical foods of the fishes Schizothorax intermedius, Diptychus dybowskii, Nemachilus stoliczkai, N. oxianus, N. kuschakewitchi, Glyptosternum reticulatum, Cottus nasalis and C. spinulosus.

Of the most important fodden for Schizothorax intermedius are mayflies (50% rate of occurrence) and caddisflies, in this order. This is also largely true of Diptychus dybowskii, with mayflies (Iron, Ephemerella, Baetis) being the most important. Blepharoceridae along with Atherix, Bezzia, and Dixa constitute about 37% in frequency of occurrence and biomass. A dominance of mayflies is also characteristic of the fodden of Nemachilus. The main component of the food of the other fishes are the larvae and nymphs of aquatic insects. The food of Salmo trutta oxianus is the same as that of Schizothorax intermedius and Diptychus dybowskii: first in biomass and frequency of occurrence are mayflies and caddisflies, second are the larvae of aquatic Diptera, especially net-veined midge larvae. The imagoes of terrestrial insects and gammarids constitute a sizable fraction of trout fodden. The composition of food supply of young trout (Salmo ischchan gegarkuni) introduced into Lake Issyk-Kul' is similar. For example, mayflies were almost the sole food (90%) of this fish in the Ton River, which empties into Lake Issyk-Kul' [8].

It is clear from the foregoing that estimates of local fish resources and adaptation of new species cannot be too effective without a qualitative and quantitative analysis and, above all, without a study of the ecology of invertebrates (mainly aquatic insects) of mountain

streams and rivers. The introduction of fish, especially trout, into Tien Shan streams is quite feasible. Despite the relatively low water mass in an individual stream, their great number adds up to a huge water basin that can be used for the adaptation of valuable species, trout in particular. It is also clear that the introduction of lake trout cannot be very effective unless the fauna of the streams and brooks where its young develop is well understood.

Some quantitive studies on mountain river fauna are now underway in the rivers of the Issyk-Kul' basin, but these and similar investigations are extremely difficult because the taxonomy of invertebrates in Tien Shan streams and rivers is not well understood. Such study of all the faunistic groups in Tien Shan rivers, aquatic insects in particular, is as urgent a task as their quantitative and ecological investigations, for the latter cannot be effective without accurate information on the species composition.

The study of invertebrate fauna of mountain streams is also of considerable value in the planning of reservoirs [9]. To begin with, the fauna of a stream or river is a source of the fauna for the future reservoir, e. g., the Chirchik River fauna proved to be the source of the Chervakskoye reservoir [15]. However, the use of characteristic forms as biological indicators is even more worthwhile. Indicator species provide information about such important aspects of the dynamics and statics of a stream or river as the permanence or transitoriness of the bed, soil mobility, salt composition, oxygen content, and danger of salinization. In dealing with such matters as forecasting the dynamics of a stream from an analysis of the fauna, one cannot limit oneself solely to a study of common forms, for occasional forms are often good indicators too. It should be kept in mind that the larvae of mayflies, caddis flies, net-veined midges, deuterophlebias and other insects sometimes live in a stream more than a year. Hence their species composition, abundance, and distribution give some idea of the year-round dynamics of the stream or river.

We shall not take up here the theoretical significance of study of stream fauna. We merely wish to note that bionics can benefit considerably from analyzing the adaptation of mountain stream forms, specifically of such a perfect apparatus as the abdominal suckers of net-veined midge larvae [27].

The mountain streams of Central Asia have very specific characteristics and do not fit into description used for Europe [5, 28, 32, 36, 38, 40]. Botosaneanu's classification for the Carpathians [21] is more suitable. They also bear some resemblances to the classification of rapid streams in North America [26, 35]. However, the Central Asian streams are so unusual that they deserve to be regarded as a special type.* They originate in high mountains in which there is a vast area of glaciers and permanent snow. Their middle reaches lie in the arid zone and over most of their alluvial-fan area are tapped for irrigation purposes. Consequently, they are comparatively short and have only a few of the vertical zones characteristic of the streams of the Alps and Cordillera. They constitute a monolithic system consisting of a few vertical segments, of which the mountain stream itself is the longest. It is somewhat simpler to compare and identify the mountain streams of Central Asia with the vertical zones of the mountain streams of the Alps and Cordillera. We do not mention the mountain streams of the Himalayas, Hindu Kush, and Kara-Korum, in which no vertical zoning of the fauna has as yet been described [19, 34, 39].

Without analyzing the vertical zoning systems of European streams described by Illies and Botosaneanu [31], we should like to point out that Tien Shan streams fit to some (but only partial) extent into schemes based on the distribution of fish, i. e., those by Thienemann (brook trout region [37]), Macan and Worthington (upper and middle salmon region [33]), and Banarescu (trout zone [20]).

A vertical zoning scheme for Central Asian rivers was suggested by V. I. Zhadin who used the Amu-Dar'ya as an example. According to this scheme, a river is divided into 5 sectors (mountain, humid, subarid, arid, and delta). However, like Muzafarov [11] Zhadin river sectors are too large. The mountain stream whose vertical division we are discussing here fit into the $1\frac{1}{2}$ to 2 upper sectors of the two schemes mentioned.

The criteria for vertical zoning are varied. They generally include the distribution of fish (cf. the studies mentioned above), followed by analysis of the same "ichthyological" zones as a function of the slope and width of the bed [29]. However, the criticism

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*V. I. Zhadin has identified a Central Asian class of rivers, to be found in the Central Asia-Kazakhstan region [3, 4].

of zoning on the basis of distribution of fish, which are highly mobile organisms, made it necessary to find other criteria. Finally, Illies [30] suggested a theoretical zoning scheme in which each zone was designated by a specific term: eurhytron, metarhytron, hyporhytron, etc. To differentiate the zones, Illies proposed a statistical method for estimating the number of invertebrate species that makes it possible to represent graphically the succession of fauna along the longitudinal profile of a river. (The lines on the graph show the changes in number of species at a series of successive points.) Without discussing Illies' method, which we believe does not take the ecological characteristics of the species into account, we shall set forth our own view on the criteria for vertical zoning of a stream.

The fundamental criteria of ecological and faunistic zoning are the fauna and ecological characteristics of the components; namely aquatic vegetation (which we are not discussing here because the Central Asian vegetation has already been quite thoroughly described [11, 17]), and the landscape and hydrological zones, as well as all the ecological conditions accessible to expeditionary and semistationary studies. In other words, the stream as a system includes all the abiotic and biotic environment. It is stated in the literature that a zone cannot be defined without taking its entire fauna into account [31]. However, the matter has received so little study that a great number of unidentified species (sp.) appear in the list of fauna of European mountain rivers, as is evident in the works mentioned above. The Central Asian streams are even less well understood, and our approach has been to use as indicators a few of the comparatively better studied groups, listing the genera and species of other groups as "auxiliary" (cf., for example, the characteristics of caddisflies given by A. V. Martynov [10]).

We have detailed information on 2 Tien Shan streams that permits us to define their vertical zones. One is from the north part or Zailiyskiy Ala-Tau (Issyk River) and the southern part of the Alay Range (Ak-Bura River). Based on the less detailed studies of other Tien Shan streams, we believe that the zoning cited below is typical of most of them. The intermontane streams will obviously differ in the greater length of the individual zones, specifically in longer middle reaches.

In our schemes we used data for only the main bed (data on the tributaries were excluded), but judging by the available information, the zoning of the tributaries duplicates on a smaller scale the zoning of the main bed.

The boundaries between the zones were drawn on the basis of the physicochemical conditions, especially the distribution of organisms used as indicators, as well as the number of species of the groups that have systematically described, and their biomass.

The question of zonal boundaries is a very complex one and Illies may well be right in determining them at the points of confluence of the main tributaries where, he points out, there is a comparatively sharp change in hydrological conditions and in the fauna [30]. The boundaries of the vertical zones in the upper and middle reaches of the Issyk and Ak-Bura rivers are likewise confined to the confluence of large tributaries.

We have not given specific names to the vertical zones of Tien Shan streams, for we preferred to use the ordinary terminology which shows the position of the zones relative to the sources of the streams. However, it must be borne in mind that the "upper" or "middle" reaches are sectors in an ecological and faunistic scheme rather than in a hydrological or any other scheme.

As far as we know, our scheme of vertical zoning of the Issyk and Ak-Bura rivers is the first attempt of this kind for Central Asian streams and we have grounds for believing that many similar features will be found in the streams of the Hindu Kush, Kara-Korum, and Himalayas. Further research will show how universal the scheme is, but invertebrates characteristic of individual zones were found in many Tien Shan streams, although the numerical data now apply only to the Issyk and Ak-Bura rivers.

Figure 1 shows changes in some physicochemical parameters and in the number of species for most components of the petrophilous fauna of the Issyk River and only mayflies, stoneflies, caddisflies and their biomasses for the Ak-Bura. The data, which pertain to August, were obtained in a comparatively short period of time, i. e., they are somewhat synchronous. They characterize the entire longitudinal profile of the rivers from the glacial sources to their disappearance in the desert zone (Issyk) or place where they empty into a plains river (Sharikhan-say; Ak-Bura). (The location of the study sites in Fig. 2 corresponds to the marks on the abscissas in Fig. 1).

There is probably no need to comment in detail on the graphs. We merely wish to point out that both rivers exhibit a similar change in water temperature: sharp rise near

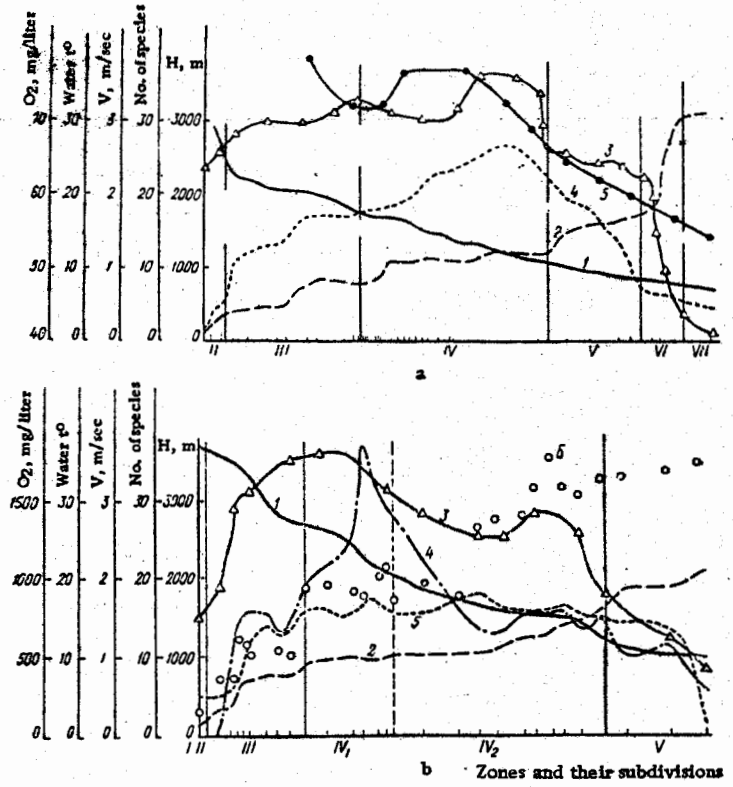

Fig. 1. Zonal change in some physicochemical and biological parameters of Tien Shan streams:

1 - Abscissa - study sites beginning with the upper reaches (left side of the curve) and as far as the lower reaches (cf. Fig. 2); a - Issyk River (Zailiyskiy Ala-Tau): 1 - elevation above sea level (river profile); 2 - water temperature in August; 3 - average surface flow rate; 4 - number of species of a litorheophilous biocenosis (mainly aquatic insects); 5 - amount of oxygen dissolved in the water; b - Ak-Bura River (Alay range); 1-3 - the same as in Fig. 1 a; 4 - number of species of mayflies, stoneflies, and caddisflies (at the study sites); 5 - biomass of the same groups (mg/dm²); 6 - air temperature in August.

their glacier sources, then a more gentle rise in the curve (upper reaches), a relative plateau (middle reaches), and a sharp rise in the lower reaches. The shape of the curve of current velocities is also similar in both rivers: increase, peak, decrease in velocity. The lines of change in number of species and biomass of the petrophilous fauna likewise are highly characteristic. Starting with insignificant quantities (near the sources of the stream) they reach a peak in the middle reaches and then drop to the lowest point in the lower reaches. All this, we believe, shows that the fauna of Tien Shan streams, like the streams themselves, is a fairly isolated system. Even when the stream changes into a plains river (Ak-Bura), its fauna, typical of a mountain stream, disappears completely, giving way to a river fauna. The swiftly flowing streams of Europe are only the upper portion of a river system, while in the Tien Shan they are an independent type of body of water.

The results of comparing changes in the physicochemical parameters of a stream and its petrophilous fauna, mainly the mayflies and net-veined midges, are presented in tabular form as a scheme of vertical zonality of the Issyk and Ak-Bura.

From the data in the table and graphs it is fair to conclude that the most significant physical parameters for mountain stream fauna are perhaps the water temperature and

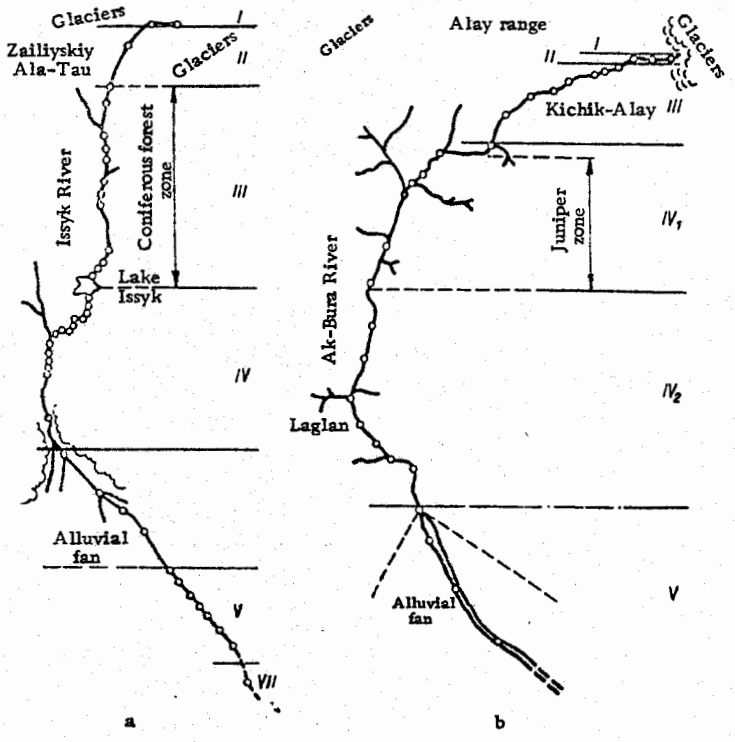

Fig. 2. Diagram showing the location of study sites from the upper to the lower reaches of the Issyk (a) and the Ak-Bura rivers (b):

I-VII - zones and sectors of zones.

current velocity and the direct effect of these factors, but not the changes they induce in the entire set of conditions (soil formation, amount of dissolved oxygen, nature of the aquatic vegetation, etc.) and, of course, the development of adaptation and biocenotic relations.

Such zones can probably be detected in most of the Tien Shan streams, as we mentioned above, but their length will vary considerably chiefly with the water mass (flow): the larger the mass, the longer the vertical zones are along the course of the stream. For example, the water temperature was 5.5° in the Talgar River (Zailiyskiy Ala-Tau) with a much larger water mass than in the Issyk River at an elevation of 1500 m above sea level, whereas it was much higher (11°) in the Issyk River with a smaller water mass (at the same altitude). All the vertical zones were shifted downstream in the first river with respect to the second. This was also true in the comparison of the Issyk and Ak-Bura rivers. Consequently, the Tien Shan streams exhibit the phenomenon that while their overall vertical zoning may be the same, the amounts of water flowing are different, and so the lengths of the zones and their position relative to various elevations may vary considerably. The smaller the flow, the shorter and higher up the zone. This naturally applies not only to the ecological conditions of the stream but also to its fauna.

Vertical Zoning of the Issyk and Ak-Bura Rivers

Zone	Geographical characteristics	Ecological conditions	Characteristic insects
		Issyk River	
I. Glacial	Glaciers, boundary of permanent snow	Absolute elevation (above sea level) 3000 to 4000 m, water temp. about 0° (0.3°). Almost no dissolved salts in the water. Ice, clastic material	None, a few Diptera are found at the very foot of the glacier Chironomidae Phoenocladius sp.* — quant: fairly most typical
II. Glacial sources, brooks	Moraine region, changes into an alpine zone	Absolute elevation 2900 to 3000 m, water temp. 2.0 to 3.0°, current velocity about 2 m/sec. Water flow less than 1 m^3/sec. Clastic material, sand, pebbles not rounded. Great soil mobility. Water turbid because of glacier-derived mud.	Diptera, Chironomidae Phoenocladius (two species)* Ephemeroptera Ameletus alexandrae Brodsky*, Trichoptera Rhyacophila sp. Plecoptera Leuctra sp.
III. Upper reaches of the mountain stream	Coniferous zone (Picea schrenkiana)	Absolute elevation 1800 to 2900 m, water temp. 3.0 to 8.0°. Current velocity over 3 to 4 m/sec. Water flow more than 1 to 2 m^3/sec. Rocks, clastic material, pebbles. Water moss here and there on the rocks. Soil mobility lower than in zone II	Diptera, Deuterophlebiidae Deuterophlebia mirabilis Edwards* Diptera, Blepharoceridae Asioreas tianschanica (Brodsky)* Ephemeroptera Iron montanus Brodsky* Rhithrogena tianschanica Brodsky Ecdyonurus sp. Tichoptera Hymalopsyche gigantea Martynov* Plecoptera Nemoura sp.
IV. Middle reaches of the mountain stream	Lower boundary of the coniferous forest, zone of larch forest and shrubs below it. In the lower part of the zone the stream emerges onto the alluvial fan	Absolute elevation 1000 to 1800 m, water temp. 8.0 to 12.0°. Current velocity more than 3 to 4 m/sec. Water flow highest, about 10 m^3/sec. Rocks, clastic material, rounded pebbles, water moss. Soil mobile only in spots. Flowering plants (occasionally) appear	Diptera, Deuterophlebiidae D. mirabilis Diptera, Blepharoceridae Tianschanella monstruosa Brodsky* Blepharocera asiatica Brodsky* Ephemeroptera I. montanus* I. rheophilus Brodsky* Rh. tianschanica Ephemerella submontana Brodsky*

			Trichoptera Rhyacophila extensa Martynov Dinarthrum reductum Martynov Apatelia copiosa McLachlan Agapetus tridens McLachlan Ag. kirgisorum Martynov Plecoptera Neoperlina capnoptera McLachlan Amphinemoura sp.
V. Lower reaches of the mountain stream	Lower boundary of the shrub zone, beginning of the steppe zone. Piedmont, alluvial fan of the river	Absolute elevation 800 to 1000 m, water temp. 12.0 to 17.0°. Current velocity slows from 3-4 to 2.0 m/sec. Water flow still high, but begins to decrease after the flow is tapped by irrigation system. The pebbles are large and small, here and there covered with mud. Flowering plants	Diptera, Blepharoceridae B. asiatica Ephemeroptera E. submontana Ephemerella sp. Iron nigromaculatus Brodsky* Ecdyonurus rubrofasciatus Brodsky* Rhithrogena sp. * Caenis sp. Baetis transiliensis Brodsky Trichoptera Hydropsyche sp.
VI. Change to a brook	Lower boundary of the alluvial fan. Steppe zone	Absolute elevation 700 to 800 m, water temp. 17.0 to 29.0° (it rises quickly downstream). Current velocity and water flow quickly decrease from 2.0 to 0.41 m/sec and from 5.0 to 0.09 m^3/sec. Pebbles, gravel, sand, and, in inlets, ooze. The river bed, which meanders, is flat and broad	No characteristic aquatic insects of its own. In the beginning of the zone: Diptera, Blepharoceridae B. asiatica Ephemeroptera Baetis issyksuvensis Brodsky* Remaining eurybionts, specifically from the Chironomidae and Simuliidae
VIII. End of the brook	Plain, semidesert zone	Absolute elevation from 700 m and below, water temp. about 30°. Current velocity 0.06 m/sec, water flow 0.014 m^3/sec. Sand, ooze, occasional flat pebbles. Cane, reed, and other flowering plants	All the mountain stream fauna disappears. Forms characteristic of stagnant water appear (Nepo cinerea (L.)

Zone	Geographical characteristics	Ecological conditions	Characteristic insects
		Ak-Bura River	
I. Glacial	Not investigated		
II. Glacial sources, brooks	Moraine region	Absolute elevation 3600 to 4000 m, water temp. 0.5 to 1.5°. Current velocity 1.5 m/sec, flow less than 1 m^3/sec. Clastic material, pebbles not rounded	Diptera, Blepharoceridae Asioreas nivia (Brodsky)* Ephemeroptera I. montanus
III. Upper reaches of the mountain stream	Moraine region, changes into an alpine zone	Absolute elevation 2700 to 3600 m, water temp. 6.2° on the average. Current velocity 2 m/sec on the average, water flow more than 1 m^3/sec. Clastic material, pebbles	Diptera, Blepharoceridae A. nivia* Diptera, Simuliidae Cnephia kirjanovae Rubzov C. jankowskae Rubzov Ephemeroptera I. montanus* Rh. tianschanica Trichoptera H. gigantea* Plecoptera Capnia elongata Zhiltzova
IV. Middle reaches of the mountain stream upper sector (IV_1)	Juniper zone (Juniperus turkestanica)	Absolute elevation 1900 to 2700 m, water temp. 9.9° on the average. Current velocity 3.2 m/sec on the average. Water flow more than 3 to 5 m^3/sec. Clastic material, rounded pebbles, rocks	Diptera, Deuterophlebiidae D. mirabilis* Diptera, Blepharoceridae B. asiatica (few, upper boundary) T. monstruosa Ephemeroptera I. montanus* Rh. tianschanica*

lower sector (IV_2)	Deciduous trees, absolute elevation at 1700 m – lower juniper boundary	Absolute elevation 1100 to 1900 m, water temp. 11.6° on the average. Current velocity 2.5 m/sec on the average, water flow about 30 m^3/sec. Rounded pebbles, not covered with mud	Diptera, Deuterophlebiidae D. mirabilis Diptera, Blepharoceridae B. asiatica* T. monstruosa* Ephemeroptera I. montanus I. rheophilus Rh. tianschanica E. submontana* E. rubrofasciatus A. alexandrae (lower boundary at the absolute elevation of 1560 m)
V. Lower reaches of the mountain stream	Alluvial fan, deciduous trees	Absolute elevation 900 to 1100 m, average water temp. 19.0°. Average current velocity 1.47 m/sec. Flow about 15 to 20 m^3/sec (the flow drops off as the water is tapped by irrigation system)	Diptera, Blepharoceriidae B. asiatica* (abundant) T. monstruosa (limited numbers) Diptera, Simuliidae Wilhelmia mediterranea Puri Ephemeroptera I. nigromaculatus* Heptagenia perflora Brodsky Ephemerella sp. * Trichoptera Agapetus tridens McLachlan A. kirgisorum Martynov Hydropsyche gracilis Martynov Glososoma dentatum McLachlan

*Quantitatively most typical forms.

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